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**Active Weld Control
Final Report**

**January 31, 1994
Bradley W. Powell
Ivan A. Burroughs**

**Contract # NAS8-38551
NASA/MSFC**



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1.0 Project Summary

ABST

Through the two phases of this contract, sensors for welding applications and parameter extraction algorithms have been developed. These sensors form the foundation of a weld control system which can provide active weld control through the monitoring of the weld pool and keyhole in a VPPA welding process. Systems of this type offer the potential of quality enhancement and cost reduction (minimization of rework on faulty welds) for high-integrity welding applications.

Sensors for preweld and postweld inspection, weld pool monitoring, keyhole/weld wire entry monitoring, and seam tracking were developed. Algorithms for signal extraction were also developed and analyzed to determine their application to an adaptive weld control system.

The following sections discuss findings for each of the three sensors developed under this contract:

- (1) weld profiling sensor,
- (2) weld pool sensor, and
- (3) stereo seam tracker/keyhole imaging sensor.

Hardened versions of these sensors were designed and built under this contract. A control system, described later, was developed on a multiprocessing/multitasking operating system for maximum power and flexibility. Documentation for sensor mechanical and electrical design are also included as appendices in this report.

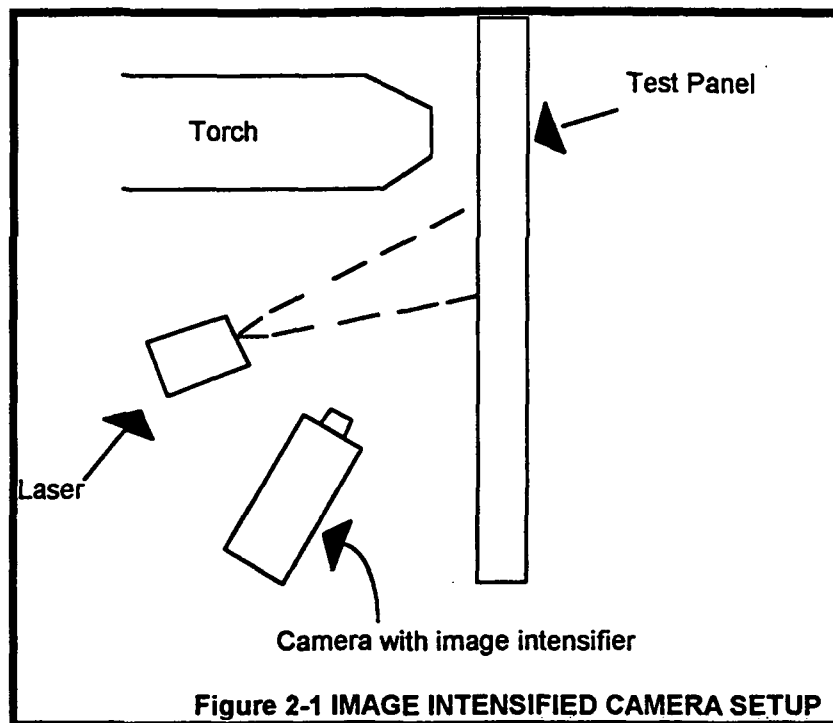
2.0 Weld Pool Sensor

2.1 Introduction

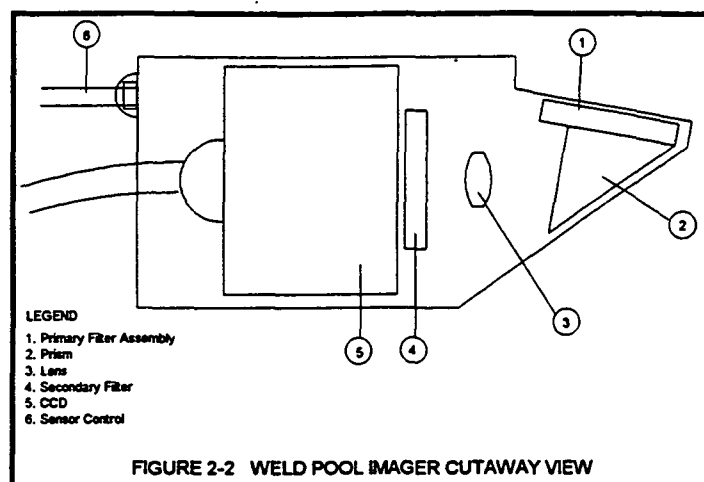
A major objective of this contract was to prototype a sensor which would view the weld pool during a weld and whose output could be processed to extract in real time, information about the quality of the weld. Pursuant to these goals a video imager which mounts under the torch and can view the arc and weld pool and algorithms to process the imagery from this sensor have been developed and tested.

2.2 Weld Pool Sensor Development

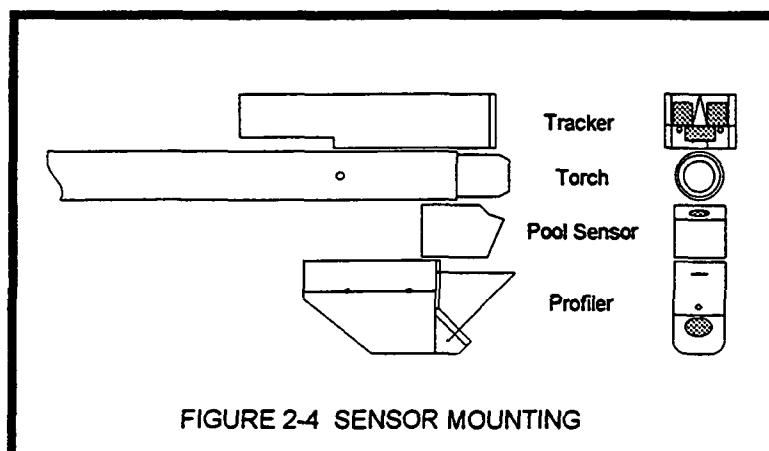
Two sensor configurations were tested. The first version, which was intended to give a view of the keyhole with the arc light suppressed, incorporated a CCD video camera with a front end image intensifier which was used as a high speed shutter, open only when a high powered (400 W) pulsed laser diode was illuminating the weld pool. Typically the highest shutter times for a CCD camera will be about 33 microseconds whereas laser diode pulse width is about 200 nanoseconds. By using an image intensifier as a shutter, camera exposure could be limited to only the period when the laser was radiating. This would reduce shutter time to about 100 nanosec, giving a signal to noise (laser illuminated keyhole image to arc light) improvement of 330 (33 microsec/100 nanosec) over a standard CCD camera. A line filter at the laser wave length was also used to further reduce the light from the arc. Figure 2-1 shows this configuration. It was hoped that this combination would reject the light from the arc to such a degree that the keyhole would be visible during a weld. However early tests made during welds to determine the best orientation of the camera and laser relative to the torch revealed that this would not work as well as was hoped. The arc intensity at the laser wave length proved to be of sufficient magnitude that it dominated the image under these conditions. Imagery using the image intensifier configuration was collected and used to begin development of processing algorithms.



During this work it was decided that images taken without the external laser illumination were just as useful as those taken with it. The laser and image intensifier were subsequently abandoned in favor of the second configuration which was only the CCD video camera with appropriate optics and electronic shuttering to view the arc and weld pool directly. Two versions of this configuration were developed. The first was a prototype to test the optics design and to optimize the viewing angle. The second version is a hardened sensor using the design optimized by prototype testing. Figure 2-2 shows a cutaway view of the latest version of the Weld Pool Sensor, while figure 2-3 is a photograph of the same.



The sensor mounts directly below the torch, above the Weld Bead Profiler in the plane of torch travel, with the optic axis looking up at the torch tip at an angle of 30 degrees off of vertical (see Figure 2-4). This angle affords a view of the arc, the torch tip and the extreme lower edge of the keyhole along with the first inch of the bead as it exits the lower region of the weld pool. Neutral density filters along with a remotely controllable variable speed electronic shutter built into the camera are used to adjust image exposure so that the brightest part of the arc will be just below or only slightly above camera saturation. Shutter times of 1/30 to 1/10000 of a second are available allowing computer controlled exposure adjustments which will cover wide range of weld conditions. With this intensity level the torch and lower edge of the keyhole are outlined against the arc. Figure 2-5 shows an image of the weld arc and keyhole taken by the Weld Pool Sensor.



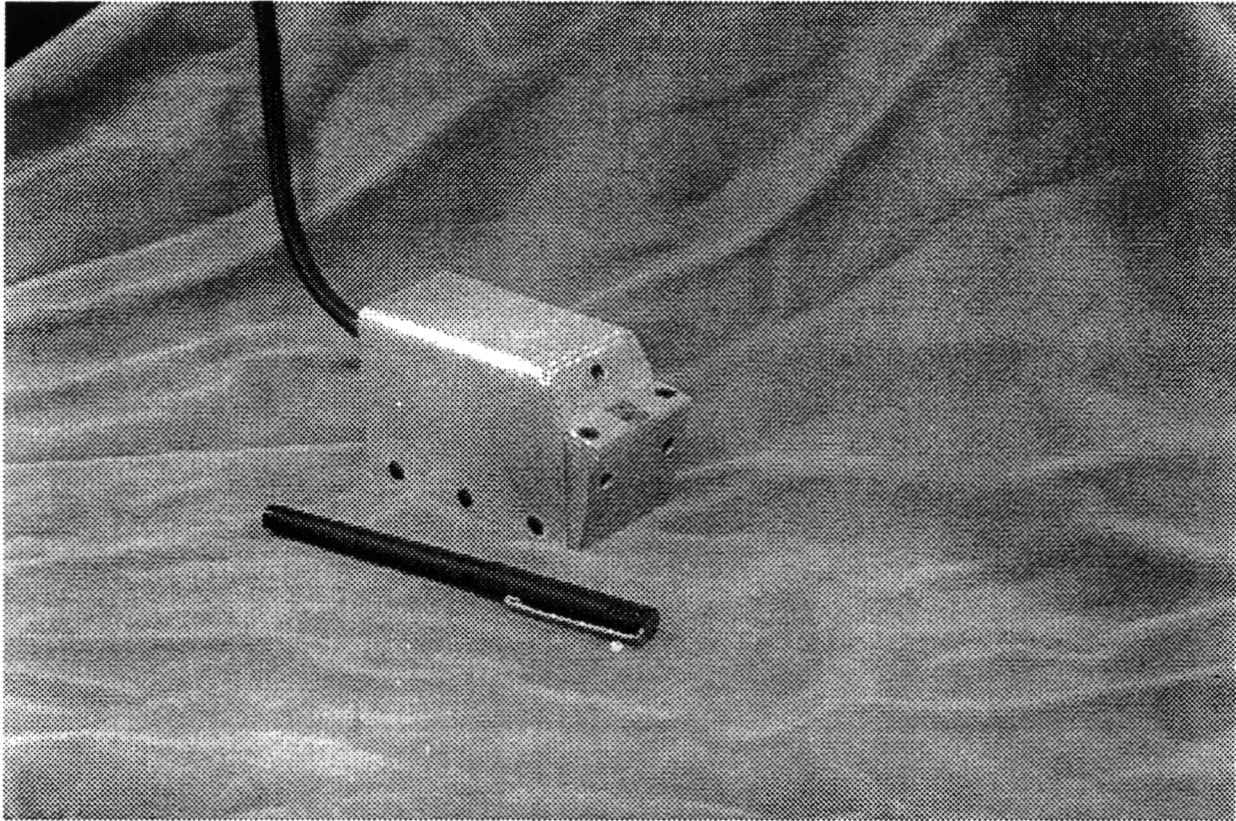


Figure 2-3 Weld Pool Imager

Two problems have been noted with the latest sensor. The first is that for material thicknesses less than 0.2" the image is hard to process. There is probably no solution with the present design since the stand off is small and the torch blocks most of the image. It may, however, be possible to repackage the sensor for a closer viewing angle or to adapt a fiber optic cable to the camera to provide an even closer view of the arc and keyhole. The second is that the image intensity was observed to vary in at least one test series. It was originally thought that this was due to the camera shutter rate being different than the VPPA rate (60Hz compared to 43Hz) so that the shutter would periodically catch the arc as it is extinguished during the transition of reversing polarity. However subsequent viewing of video taken with the image intensified version of the sensor which was also shuttered at the same rate revealed that the dimming phenomenon was not apparent in that video which was taken at an earlier date. As of this writing we have no satisfying explanation but the problem is being investigated.

2.3 Weld Pool Parameter Extraction Algorithm Development

Algorithms have been developed which extract information from the video imagery about the weld pool and the resultant weld bead. This information includes the cut delta, bead width and bead center relative to the torch. The first step in processing the video imagery from the weld pool sensor is edge enhancement so that the torch and trailing side of the keyhole (both are outlined by the arc) will be more prominent.

Figures 2-6a and 2-6b show respectively examples of the video before and after edge enhancement. The camera was mounted such that direction of torch travel is toward the left of the images. Table 2-1 is the convolution matrix used

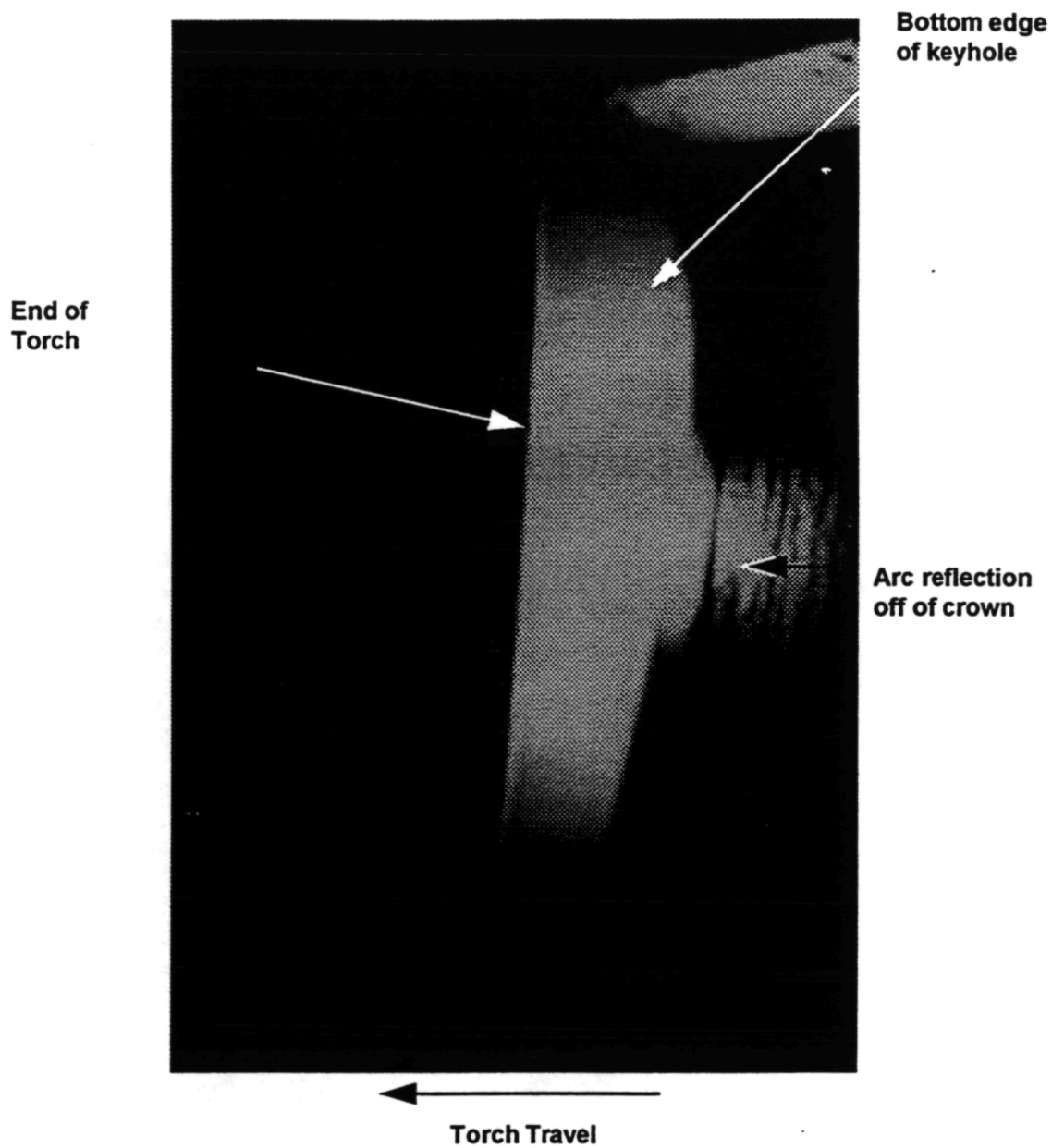


Figure 2-5 Weld Pool Image

Torch Travel



Outside of cut

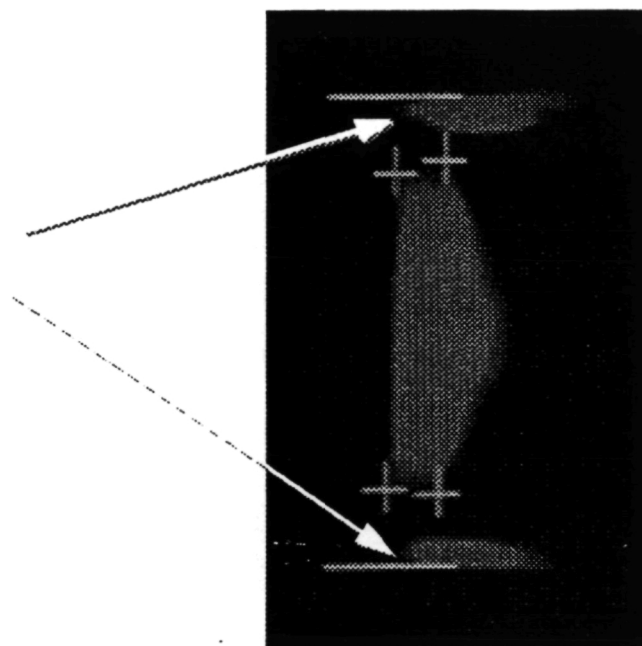


Figure 2-6a
Typical Weld Pool Image
Before Edge Enhancement

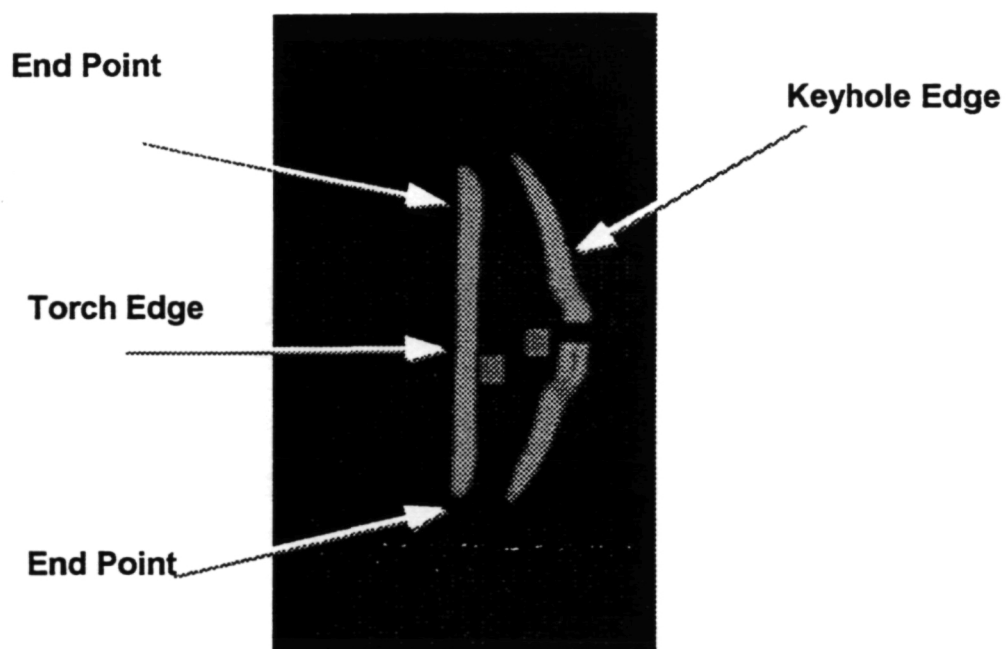


Figure 2-6b
Typical Weld Pool Image
After Edge Enhancement

0	1	0	0	-1	0
-1	0	1	-1	0	1
0	-1	-2	2	1	0
0	-1	-2	2	1	0
-1	0	1	-1	0	1
0	1	0	0	-1	0

TABLE 2-1 EDGE DETECTION CONVOLUTION MATRIX

for edge enhancement. Referring to figure 2-6b, the left most feature is the edge of the arc seen against the end of the torch while the trailing edge of the keyhole is the double vertical band to its right. Figure 2-7 shows a stylized representation of the edge enhancement results with processed features labeled.

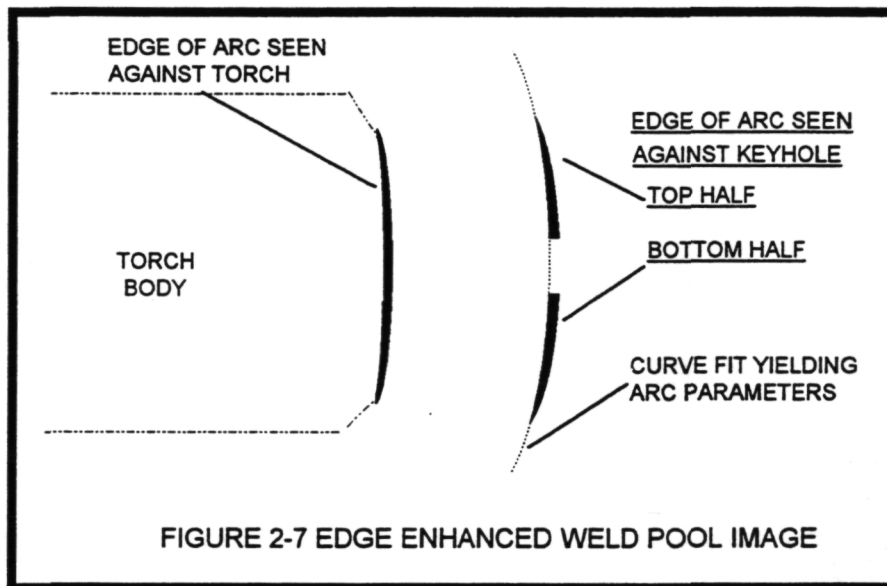


FIGURE 2-7 EDGE ENHANCED WELD POOL IMAGE

Edge enhancement, achieved by convolving individual pixels in the image with a 6X6 matrix, is not performed on the entire image but only on pixels as required by the search algorithms which find and process the torch and keyhole edges. The torch is located by starting at the middle row of the image and searching to the right in the image until an edge is found that is wide enough to qualify as the torch edge. If no edge is found after searching for a specified distance along the scan line the search drops down 10 lines and continuing this

pattern until about 25% of the image has been searched. If no qualifying edge is found an error is generated, the image is rejected and another is taken. When a valid edge is found the coordinates for the edge are passed to a function which finds the loci of the centroid of the pixels which are above a predetermined threshold along each scan line in the edge. These loci are saved in an array as x (col.) and y (row) coordinates of the edge centroids and are fit with a second degree polynomial. It was eventually determined that the mid and end points of the torch edge were sufficient to characterize the torch position.

Since the arc will reflect off of the weld crown for some distance after the keyhole, a region in the center of the keyhole edge is ignored so that after proper thresholding of the edge enhanced image the keyhole edge is split in the middle with the two halves found separately, the top half first. The two halves are found in the same manner that the torch is found except that the search starts at the torch end for the corresponding half of the keyhole edge. An array containing the x (col.) and y (row) coordinates of the edge centroid loci is generated for both halves of the keyhole edge. As with torch edge centroids, a second degree curve fit is made for the data set including both halves of the keyhole edge with the abscissa origin at the torch mid point.

The coefficients from this fit are used to characterize the keyhole edge. The constant term of these coefficients, together with the corresponding term from the torch loci curve fit, gives a measure of stand off. The first order coefficient was shown to correspond to the bead cut delta and the second order coefficient has some relation to bead width. It was found that using the mid point between the torch edge end points, shown in figure 2-6b, will describe the center of the arc which as will be shown correlates very well to the center of the bead with respect to the center of torch and allows detection of weld bead offset relative to the centerline of the torch.

Three approaches to determine bead width have been explored. The first attempts to correlate bead width with keyhole curvature, a measure of which is given by the second order coefficient of the keyhole polynomial curve fit. Keyhole curvature and bead width should inversely correlate since a smaller keyhole will give a higher curvature while a larger keyhole will give a smaller curvature. It was found that the curvature measurement while fairly accurate when it was correct, was totally incorrect at times and therefore unreliable. One reason for

these errors is because a higher bead crown will cause the center of the detected keyhole edge to be more in line with the outside edges producing a smaller curvature while a lower bead crown will do just the opposite. This causes variations in curvature measurement which have nothing to do with keyhole size. Severe undercuts also cause the same problem for basically the same reason.

The second method relies on the fact that the outside edges of the cuts reflected light from the arc making them visible in the test weld imagery, see figure 2-6a. An algorithm was developed which found these reflections and calculated bead width based on their separation in the image. While this method proved to be accurate when the cut reflections were present it was determined that they were not always in evidence in the imagery. This method however was an improvement over using the second order coefficient of the keyhole polynomial curve fit in that it is possible to determine if the cut reflections were present thus giving confidence to the identification of valid measurements.

The third method developed takes a measure of the arc width as determined by a brightness threshold applied to the arc image along a search path that moves in toward the arc orthogonal to the weld bead, the theory being that a wider arc will produce a wider bead. The algorithm starts at a point to one side of the arc and searches in toward the arc until an amplitude threshold is exceeded. This is repeated for the other side. The separation of these two points is proportional to the arc width and therefore bead width. This method has not been tested adequately to be able to determine how well it performs

2.4 Weld Pool Sensor Testing

Test sessions were conducted at different stages of weld pool sensor development in order to gain data for sensor and algorithm design. The first of these tests (11/13/90) was using a simple CCD camera to obtain preliminary measurements of arc intensity versus current and voltage. Another objective was to get some feel for what would be seen by a weld pool sensor when under cuts were present in a weld. The data gathered during this session was used, as inputs for developing the design criteria of the image intensified camera as well as sample video to start preliminary algorithm development. It was determined from this video that

edge enhancement and curve fitting the keyhole edge appeared to be a good approach for feature extraction.

The next series (1/28/91) was to test the newly developed image intensified camera in a welding environment and to collect some preliminary video for a top side keyhole imager to be incorporated into the seam tracker. It was determined from these tests that the image intensifier would function well in the presence of an arc with no discernible operational problems. Some preliminary testing of the 400 Watt laser was also conducted at this time.

In order to determine which extractable features from the weld pool imagery relate to weld bead features such as cut delta and bead width and to weld parameters such as arc current, arc voltage and travel rate, video was collected during test welds (4/19/91) where for each weld one of the several weld parameters was varied. The weld parameter values were printed by the weld controller during the weld and later converted to data files which could be compared to information extracted from the weld pool imagery for analysis. Welds were also made in which the torch was rotated to produce cuts in the weld bead. The test panels for all the welds were saved and later scanned with the Weld Bead Profiler to obtain the bead features along the weld as a function of distance from the weld start point. The Image intensified camera with the 400 Watt laser as an illumination source was used for this test series. After reviewing the imagery from these welds it was decided not to pursue the image intensifier and laser as neither seemed to be contributing substantially to the quality or usefulness of the imagery. It was also this imagery that was used for the main development effort of the processing algorithms.

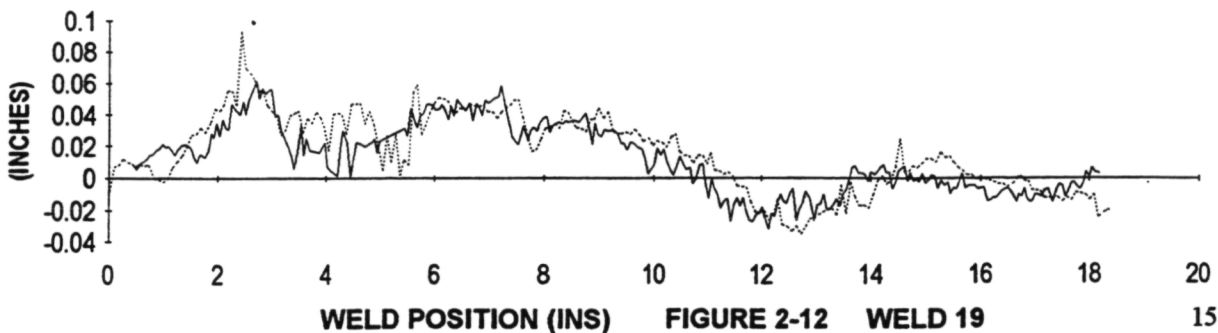
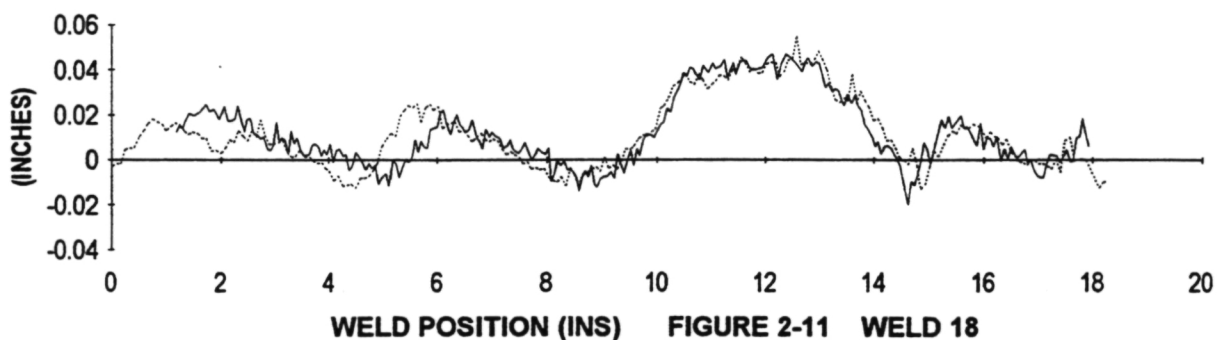
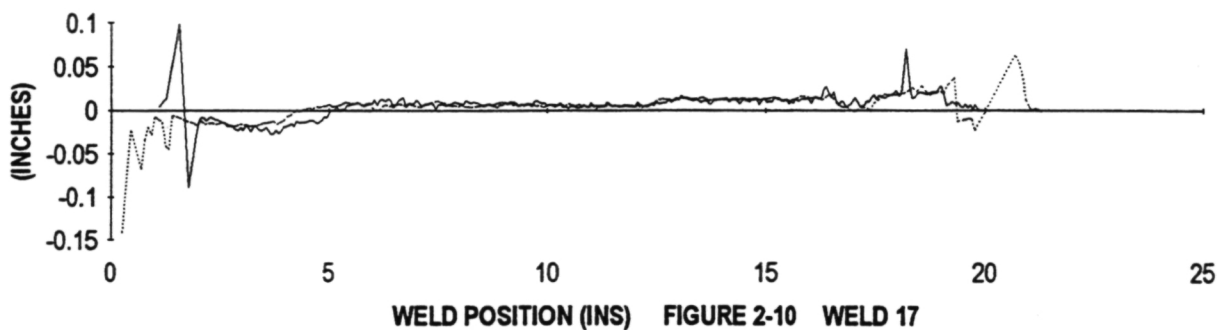
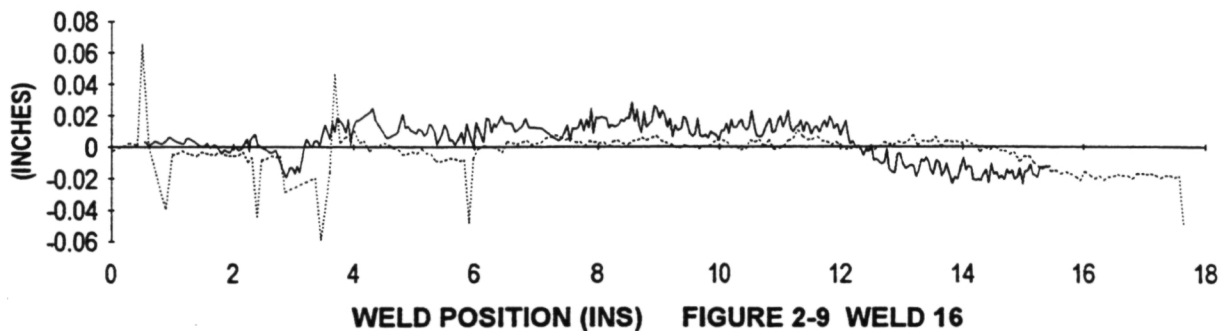
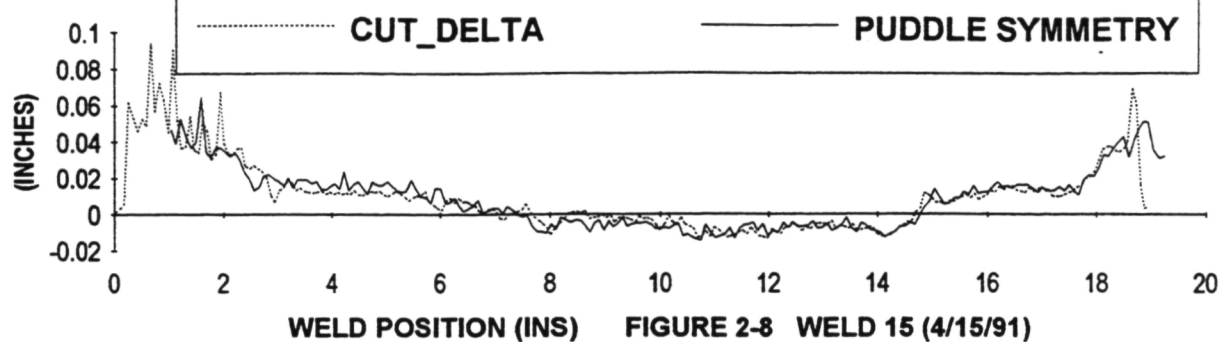
It was determined from these tests that of the information extracted from the imagery the strongest relationship was found between the first order coefficient of polynomial curve fit of the keyhole edge and the weld bead cut delta. This coefficient gives a measure of the keyhole symmetry which will be skewed when cutting is taking place. Indeed, as can be seen in Figures 2-8 through 2-12, when the first order coefficient is properly scaled and offset there is a strong correlation with the cut delta as measured by the profiler. The same scale factor and offset were used for all the symmetry measurements before plotting with the cut delta, as measured by the profiler. These measurements have not been scaled. The X axis of the plots is derived from the profiler measurements and show the distance in inches from the weld start

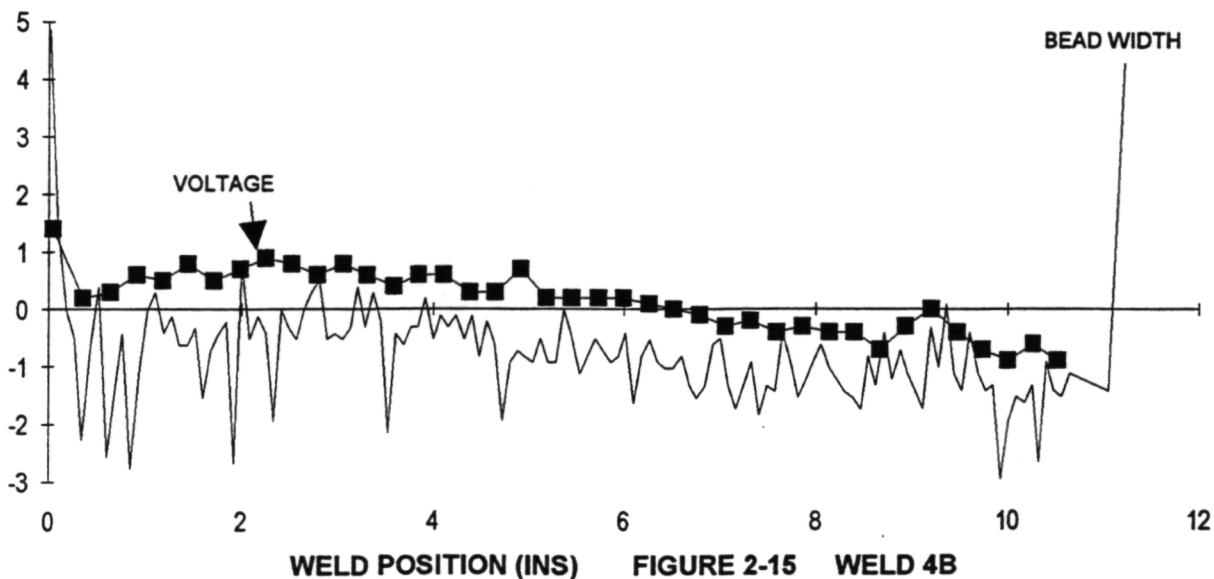
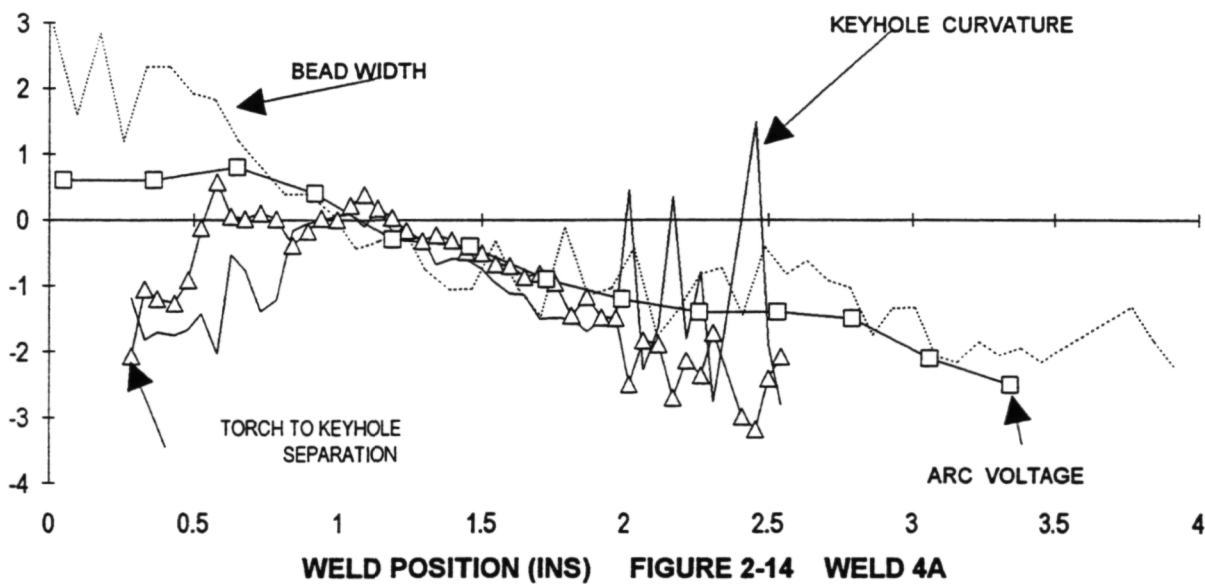
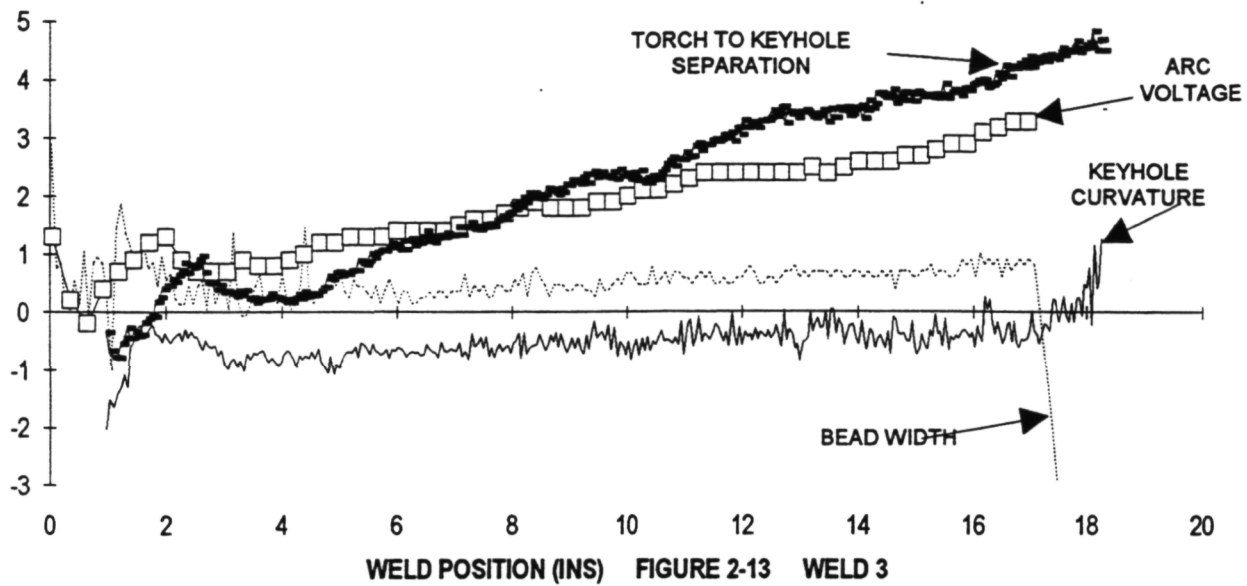
point. The Y axis is also inches. Since the keyhole symmetry measurements were made from video which contained no distance information, but from which only the time from the first evidence of weld activity could be derived, it was necessary to scale the time base of the video by the known weld velocity and then offset this distance to compensate for the uncertainty of the elapsed time between the arc being struck and actual movement of the torch. The same time scale was used for all plots while the offsets varied slightly. Table 2-2 shows the scale factors and offsets used in these plots.

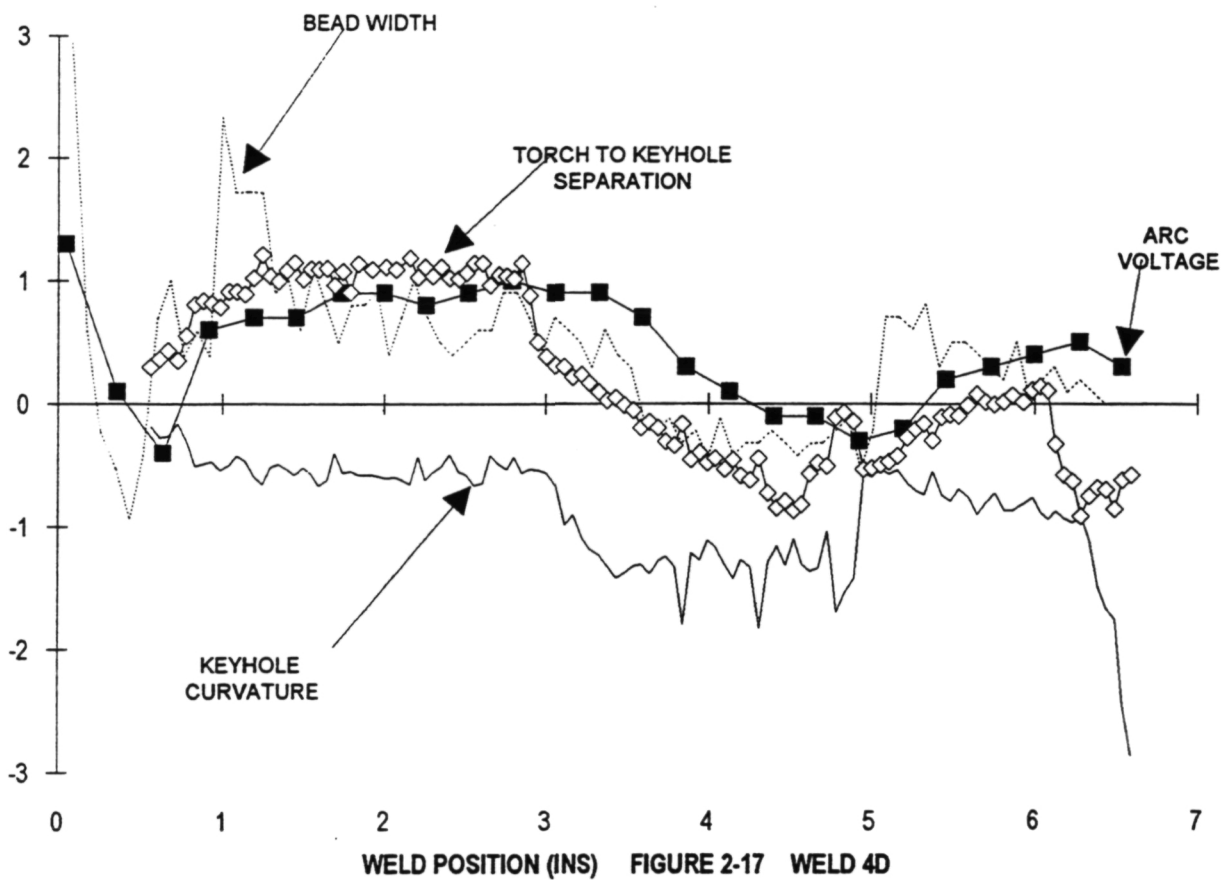
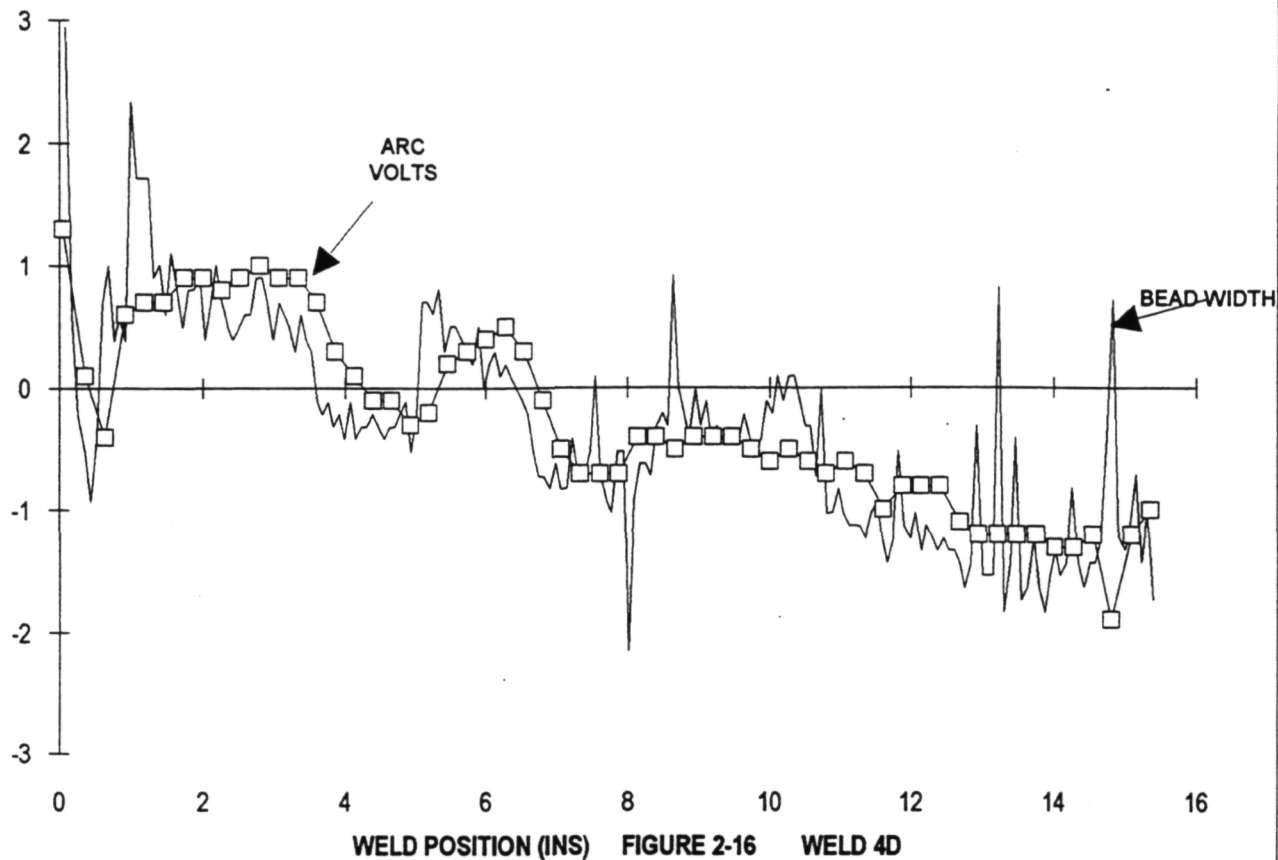
WELD CONSTANTS	WELD 15	WELD 16	WELD 17	WELD 18	WELD 19
VELOCITY (IN/SEC)	0.138	0.138	0.138	0.138	0.138
X-AXIS OFFSET	0.0	0.0	0.6	-0.3	-0.3
SYMMETRY SCALE	-0.3	-0.3	-0.3	-0.3	-0.3
SYMMETRY OFFSET	0.015	0.015	0.015	0.015	0.015

TABLE 2-2 KEYHOLE SYMMETRY SCALE FACTORS AND OFFSETS

Two other features extracted from the imagery were a measure of the keyhole curvature given by the second order coefficient of the keyhole polynomial curve fit and the torch to keyhole separation in the video given by the difference between the constant terms of the curve fit coefficients of the torch and the keyhole edges. The four parameters arc voltage, bead width, torch-to-keyhole separation and keyhole curvature features should all be related. Voltage will effect separation (stand off) and bead width of which separation is a measure. This relationship can be seen in Figures 2-13 through 2-17. Arc voltage was taken from the weld parameter printouts, while bead width was found by profile scanning of the panels. As can be seen and was noted above the inferred keyhole curvature and bead width do correlate somewhat but as was noted the curvature measurement is often incorrect with no reliable indication that it is so. The torch to keyhole separation is a measure of stand off which is related to arc voltage for a given current and can be seen to correlate fairly well. However while for an adaptive weld control system the ability to extract stand off and therefore arc voltage could be important, this was not pursued since the relationship is obvious and extraction of the information is straight forward.







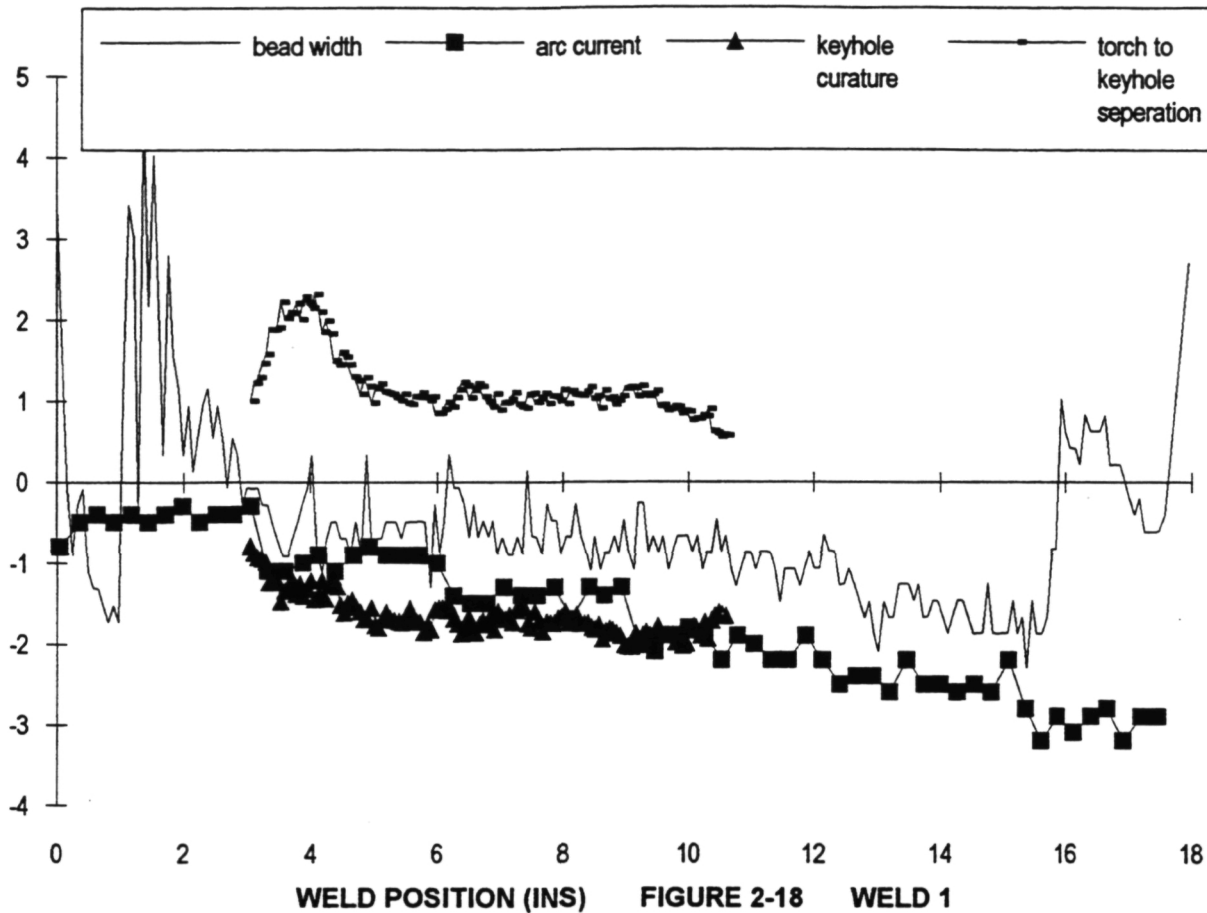


FIGURE 2-18

WELD 1

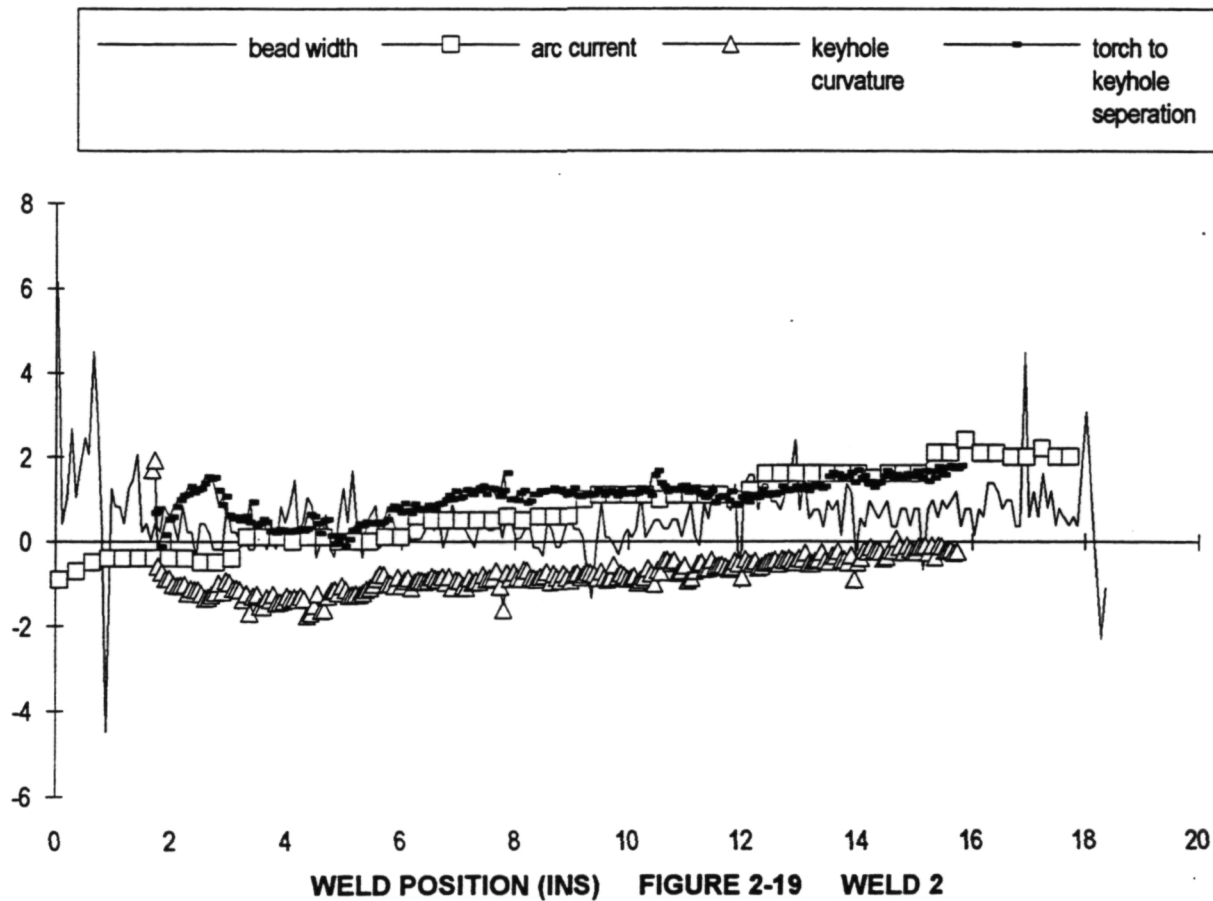


FIGURE 2-19

WELD 2

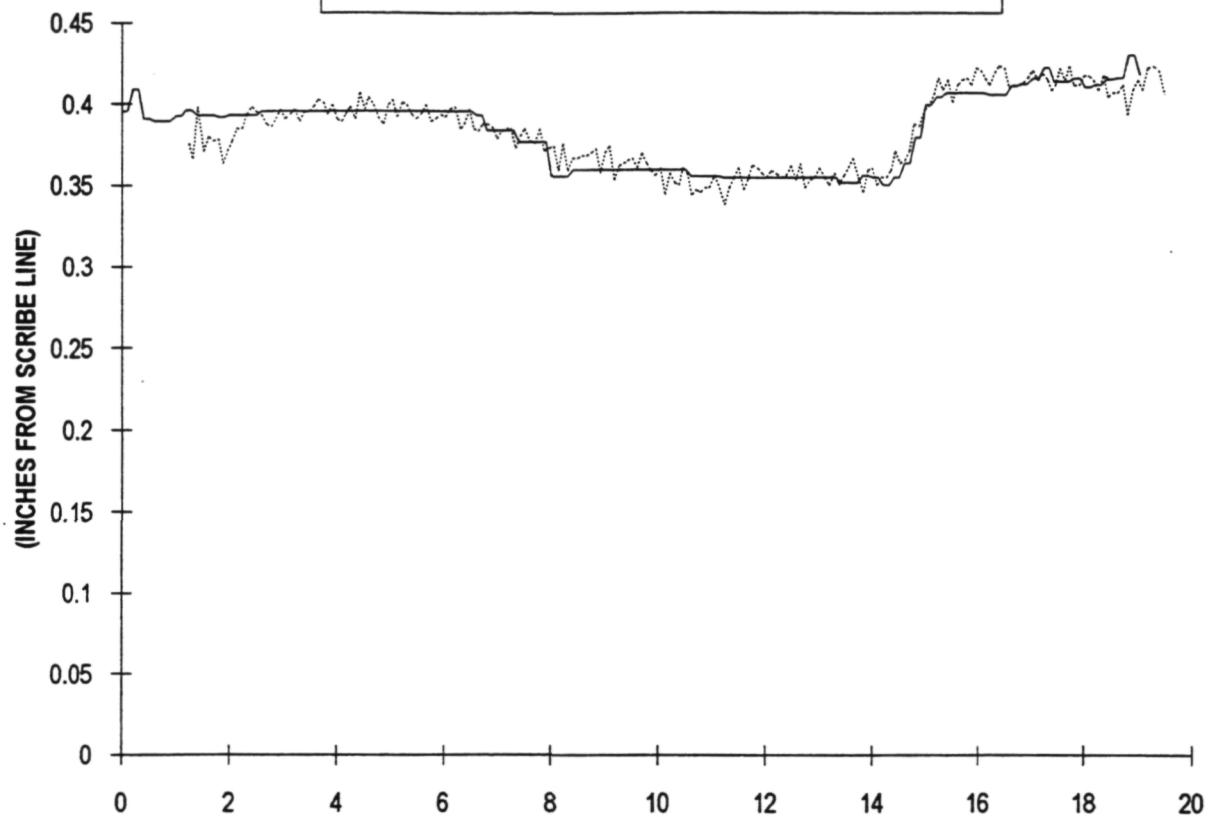
Arc current was compared to separation, bead width and keyhole curvature but the results were not entirely convincing although some small correlation can be seen, at least in the fact that the general trend is in the same direction for these variables. Figures 2-18 and 2-19 show these results for two welds where the current was varied.

The results of using the mid point between the torch edge end points to describe the center of the arc correlates very well to the center of the bead as can be seen in figures 2-20 and 2-21. In these plots the bead center was manually measured at 0.1" intervals relative to a scribe line parallel to the direction of weld travel made on two of the weld plates from the test series noted above. The torch edge mid point loci were scaled and offset for comparison. Both plots used the same scale and offset.

After the weld pool imager was redesigned to not use the image intensifier, the new version was tested (2/5/72) to determine optimum lenses and filters. This was done in conjunction with a test series conducted mainly for the seam tracker and profiler.

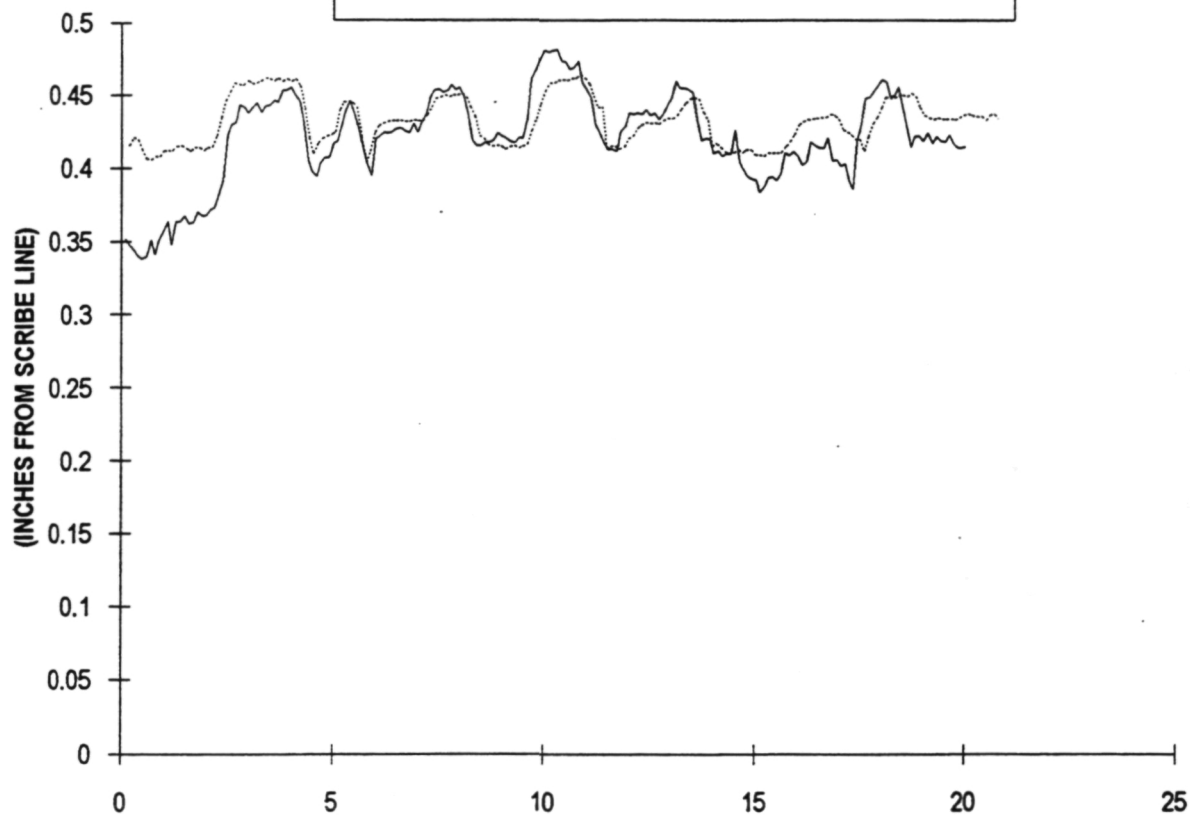
The final tests were carried out as part of the Design of Experiment weld parameter excursion study conducted at the NASA weld Lab (Summer and Fall 1993). Imagery from the Weld Pool Sensor was processed in real time and logged along with data from the Weld Bead Profiler and the Seam Tracker. Weld pool symmetry (first order coefficient of curve fit of keyhole edge) was compared to cut delta from processed Profiler data. The results are shown in Figures 2-22 through 2-39. Scale and offset factors, identical for every plot, have been applied to the weld puddle symmetry data. Although the correlation between cut delta and symmetry does not seem to be as high as in earlier test there is still a fair degree of correlation especially when cut delta is greater than 10 mils. There are two reasons why earlier test yielded seemingly better results. First the earlier test generally had larger cut deltas so that 5 or 10 mil inaccuracy in the scaled symmetry were not as readily apparent. Secondly, the intensity fluctuation of the arc in the video as discussed in Section 2-2 above will cause more processing errors to be made. However, while it may not be possible in general to use weld pool symmetry to precisely predict cut delta, symmetry can be used in a null point control scheme where cut delta is kept within certain bounds.

— BEAD CENTER ARC CENTER



WELD POSITION (INCHES) **FIGURE 2-20** **WELD 15 (5/15/91)**

— BEAD CENTER ARC CENTER



WELD POSITION (INCHES) **FIGURE 2-21** **WELD 11 (11/13/90)**

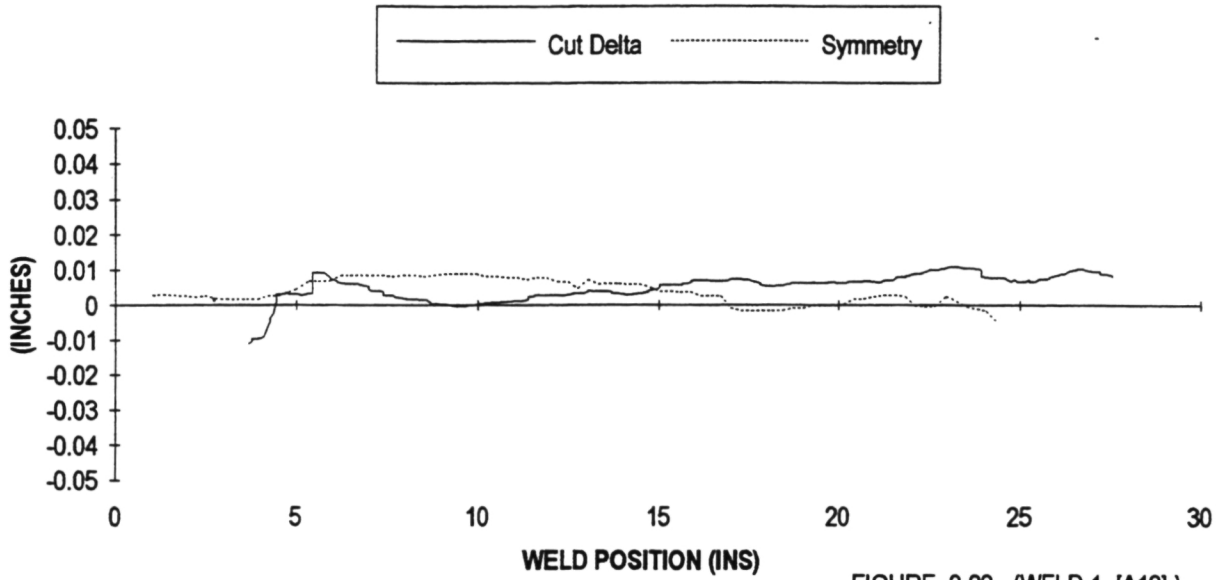


FIGURE 2-22 (WELD 1 [A12])

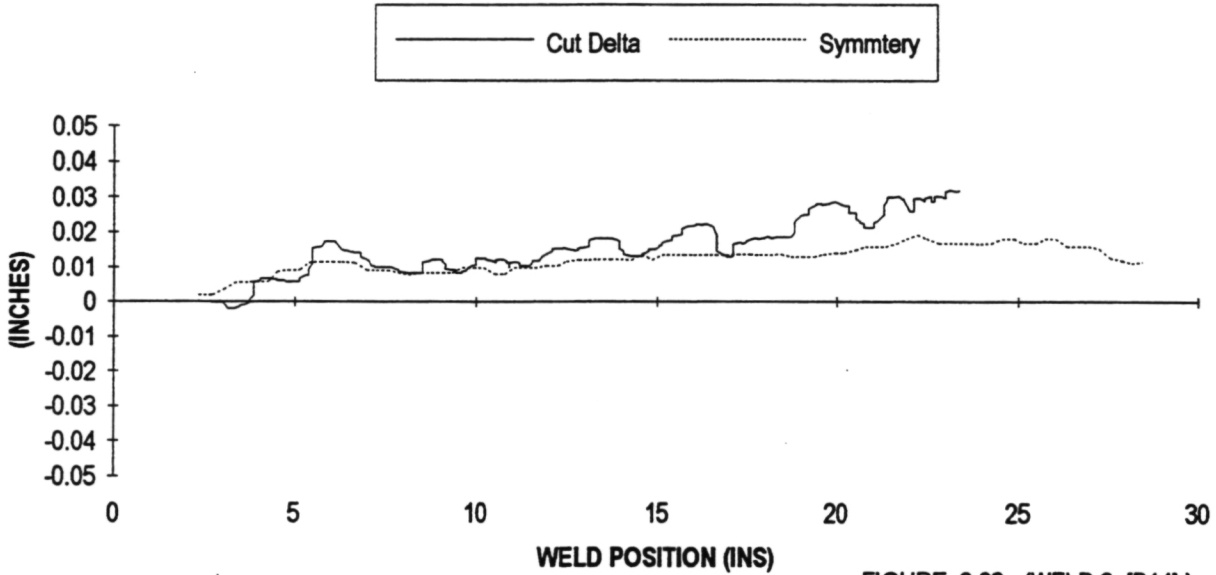


FIGURE 2-23 (WELD 3 [B14])

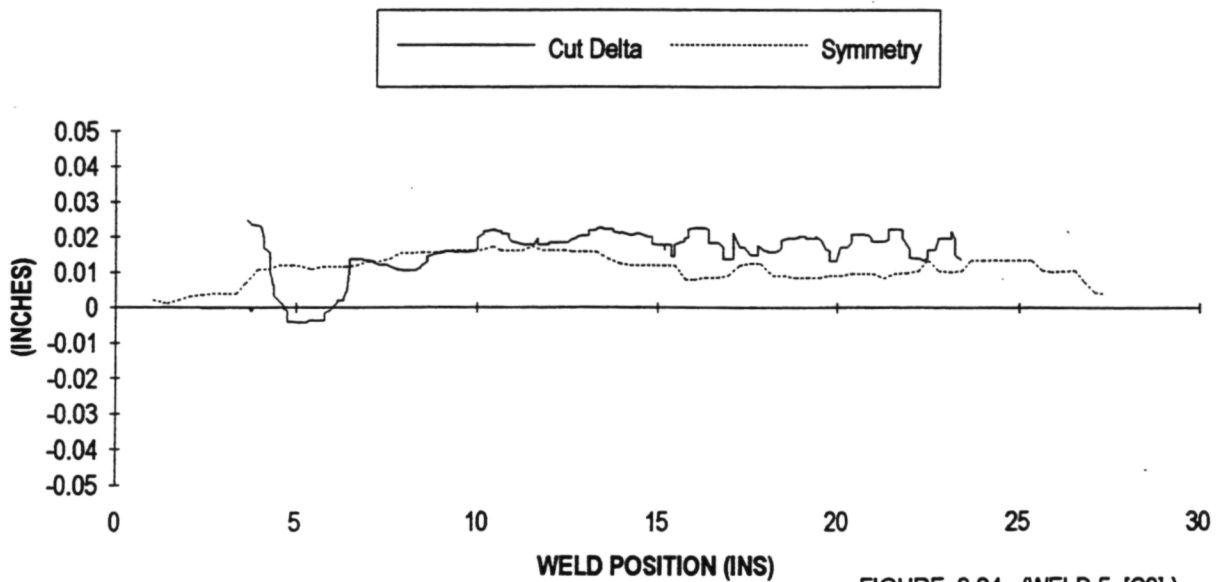
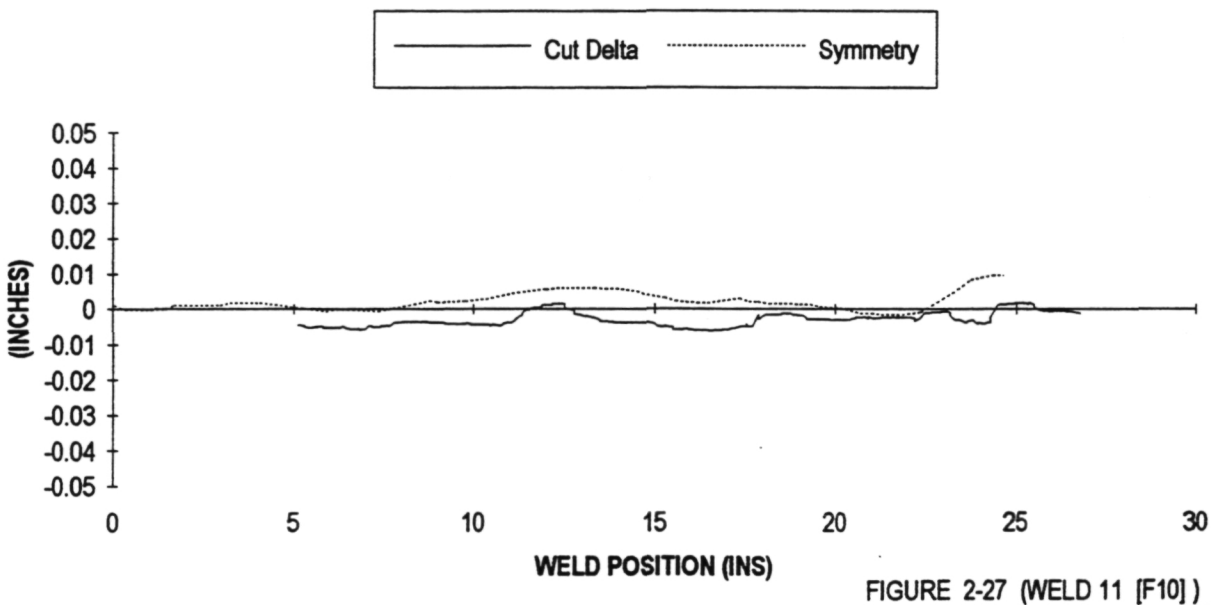
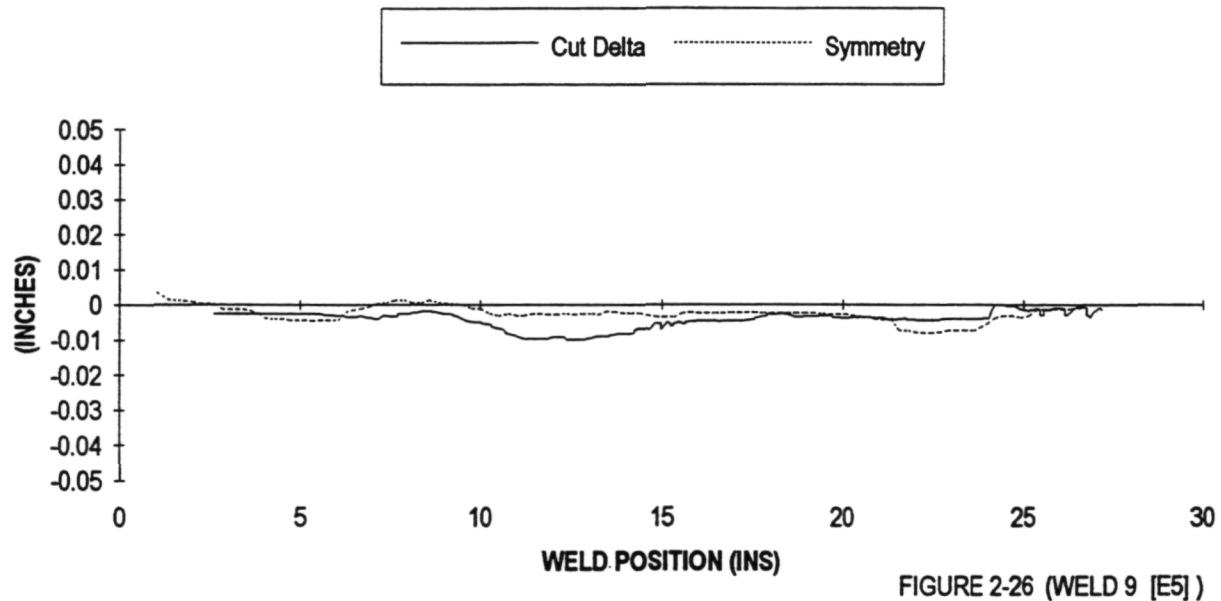
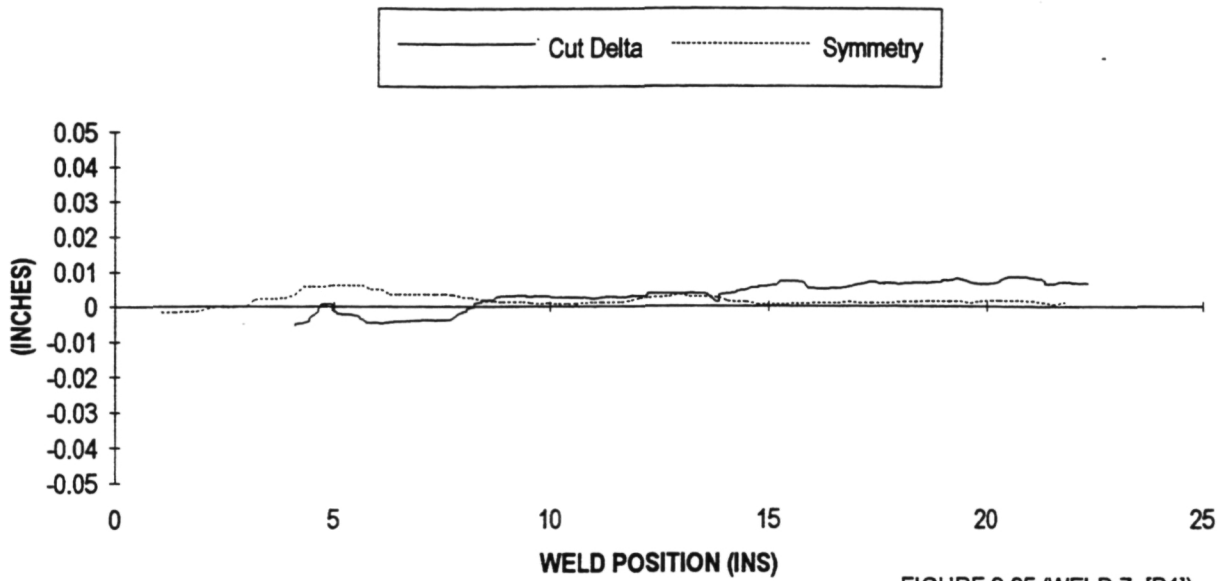
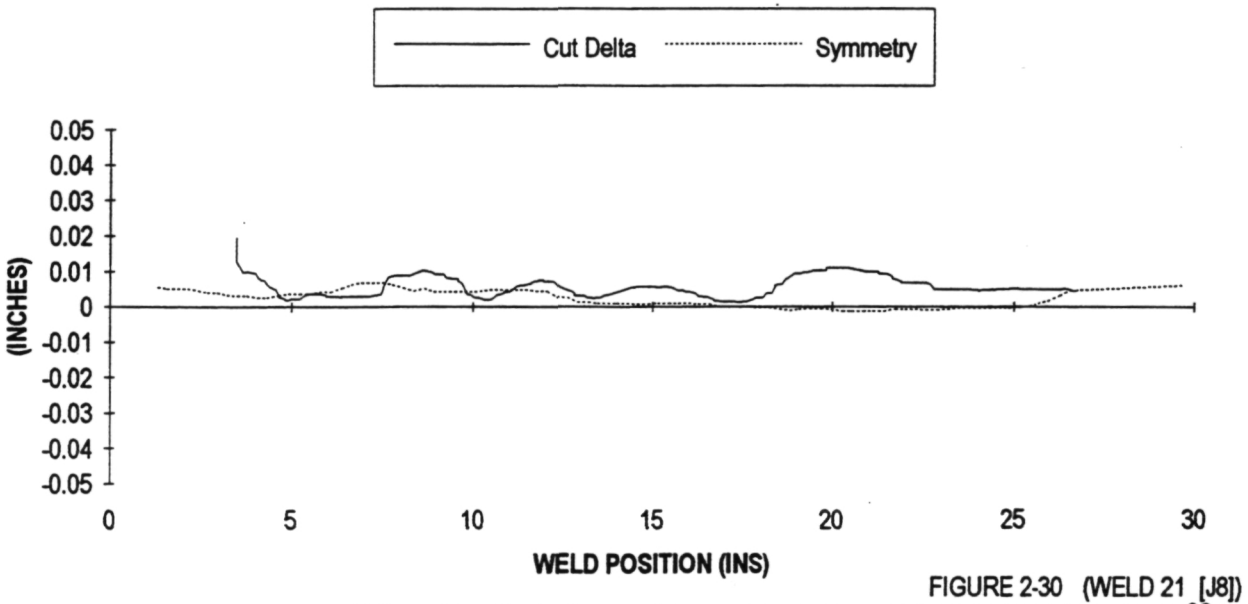
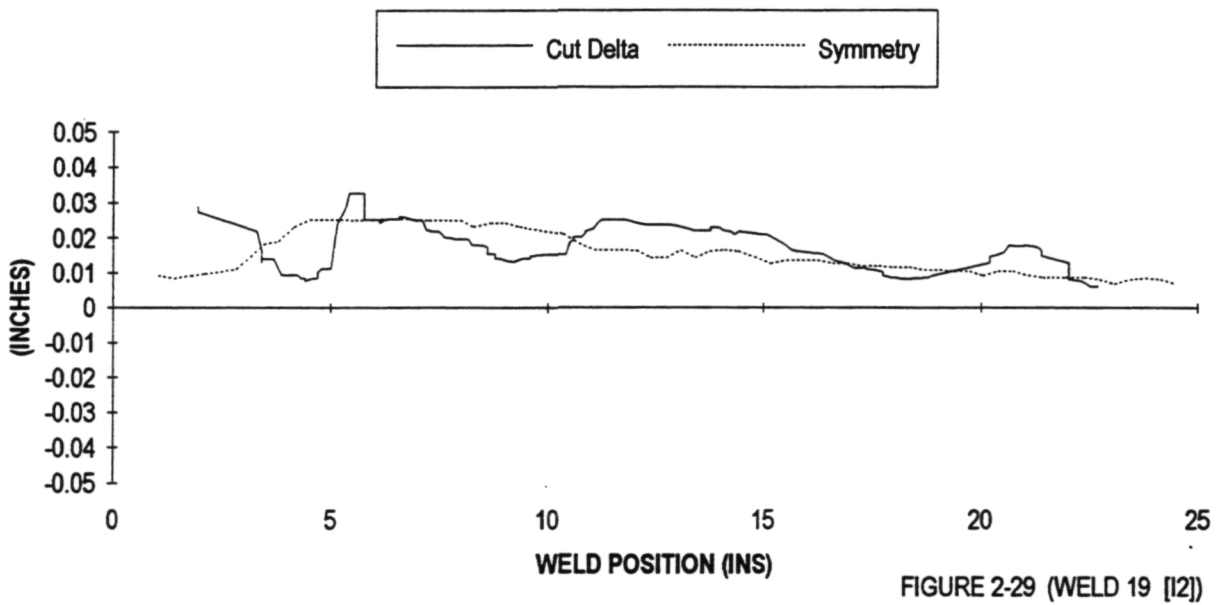
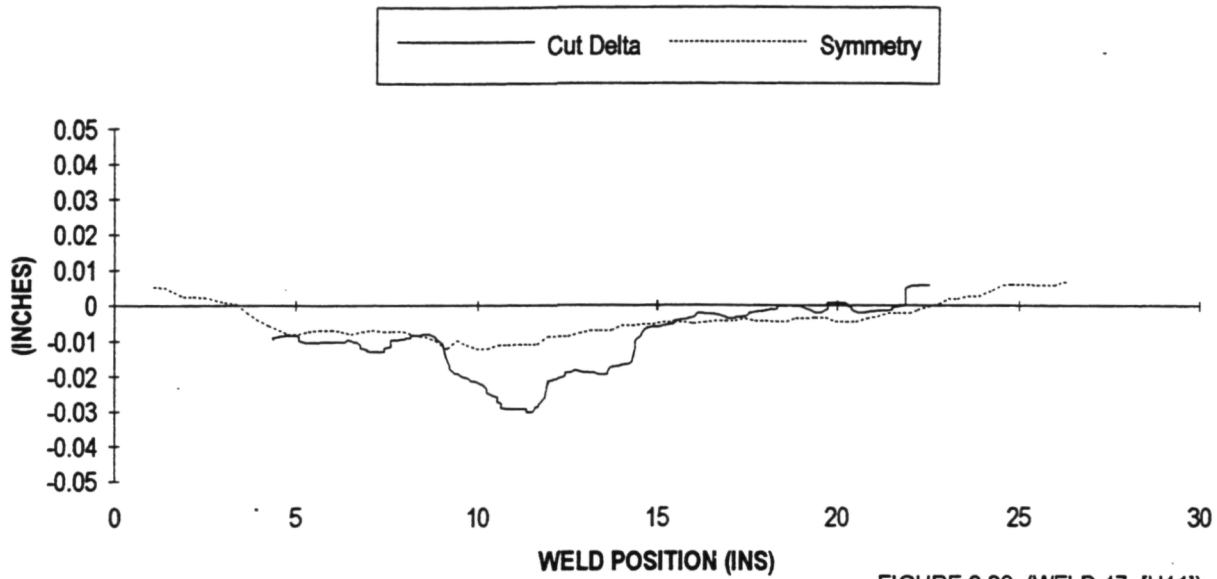
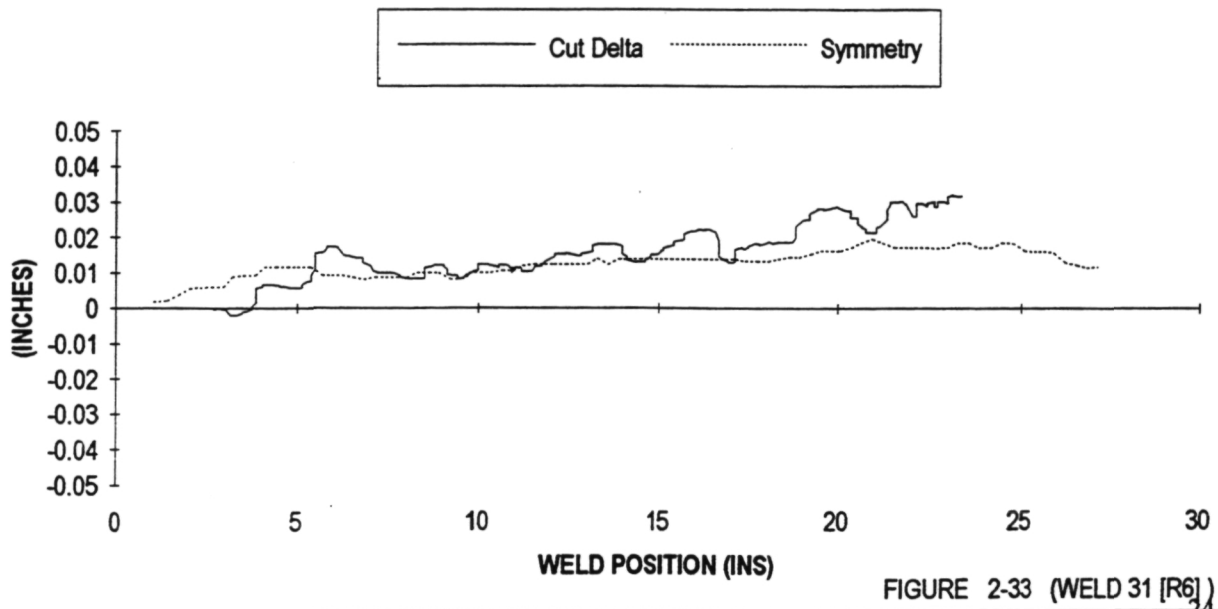
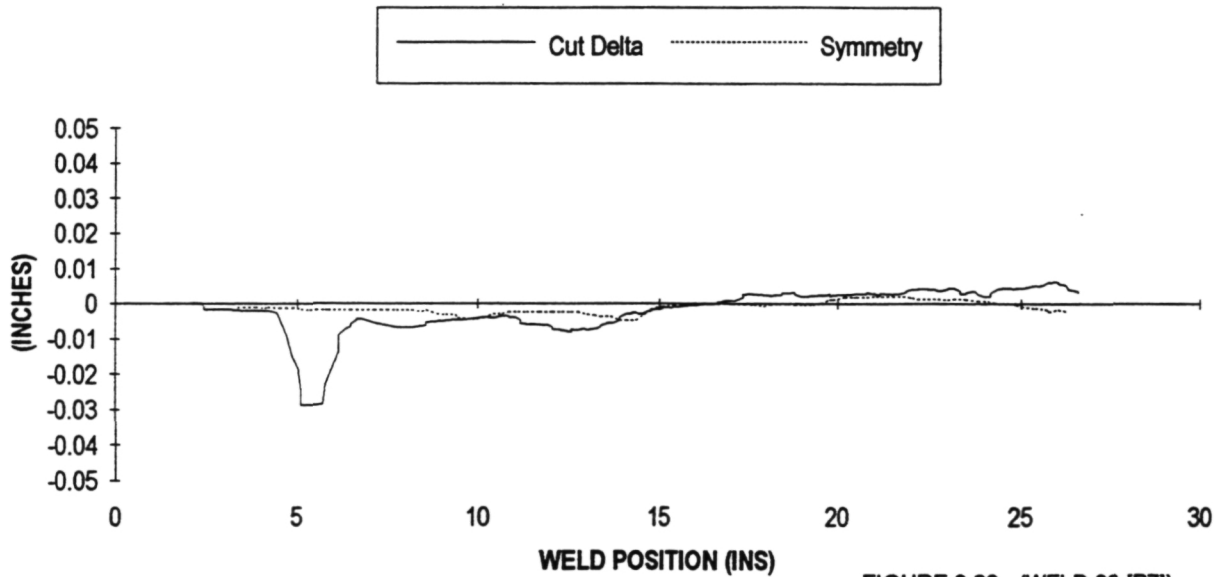
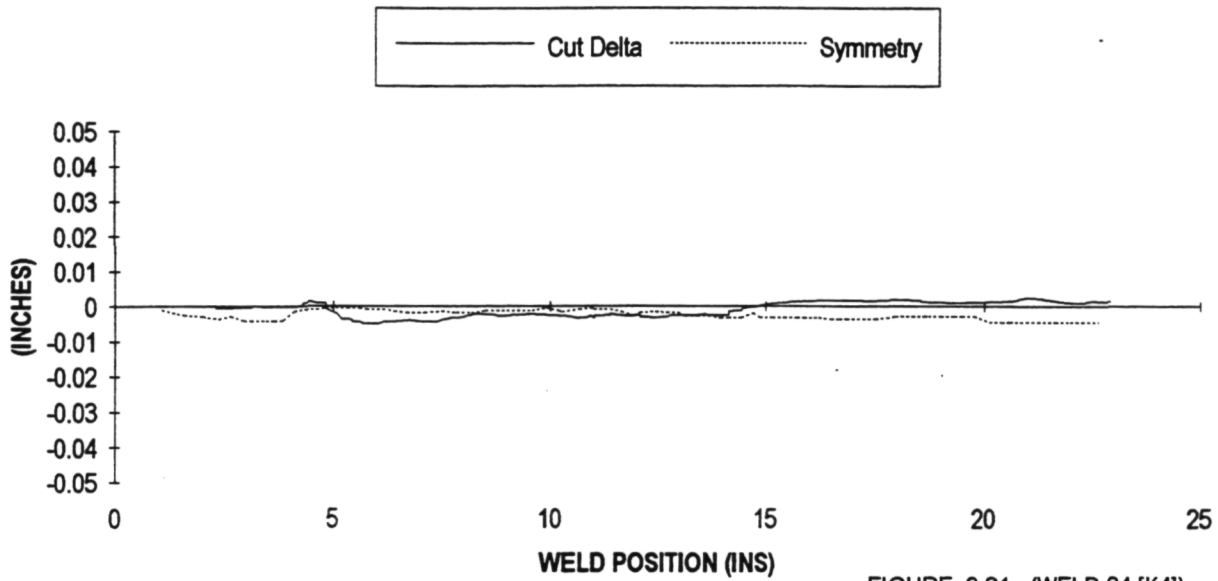
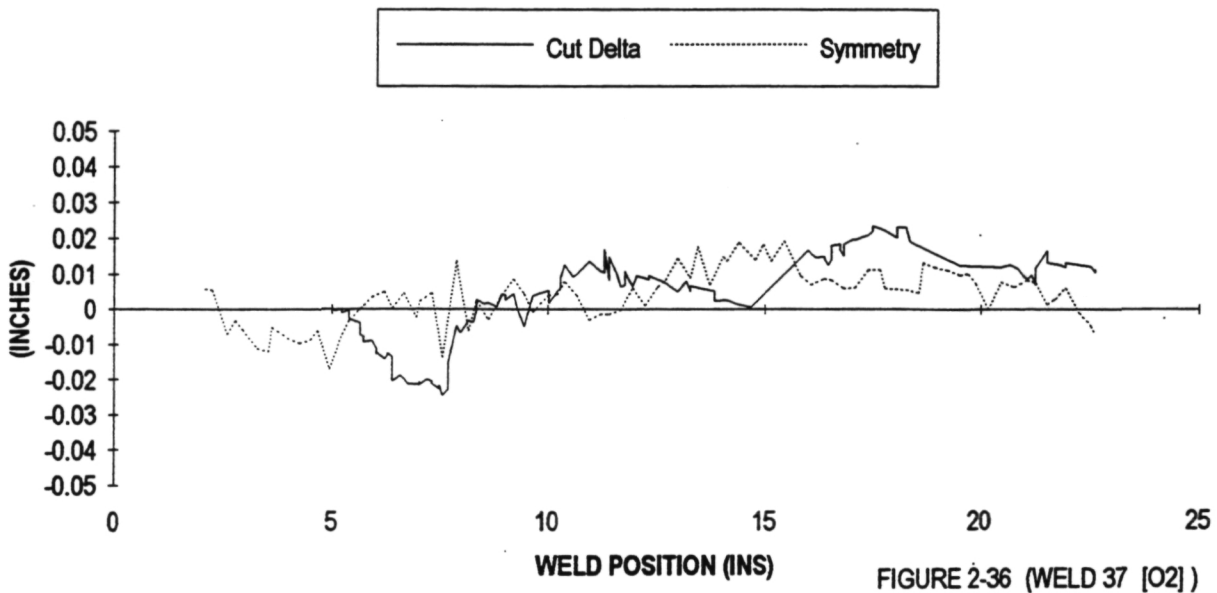
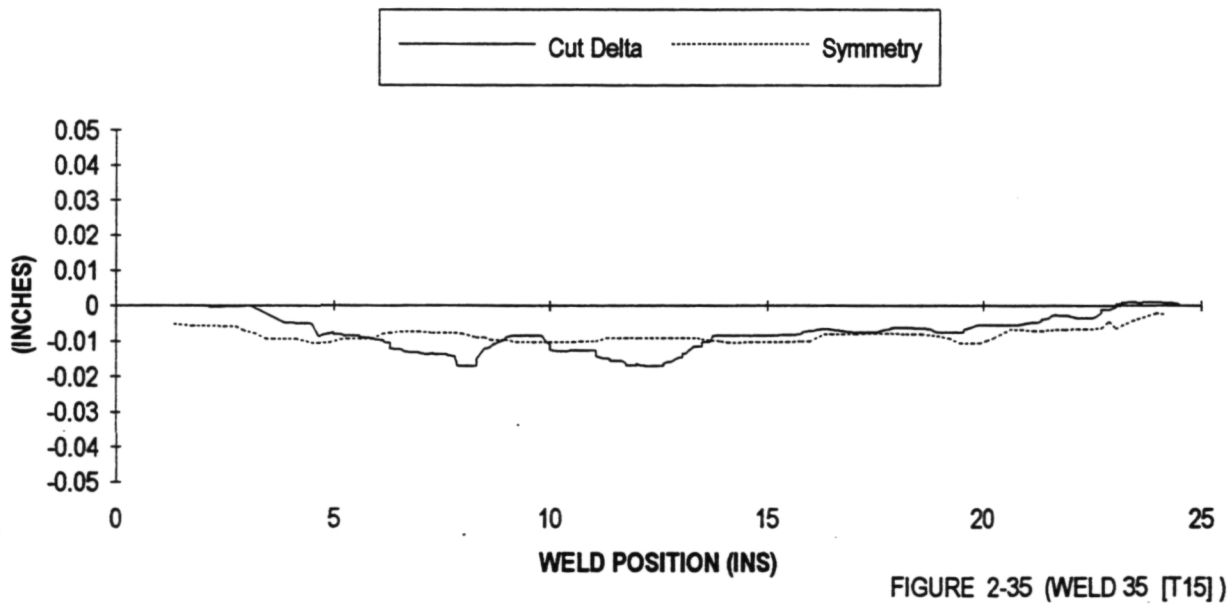
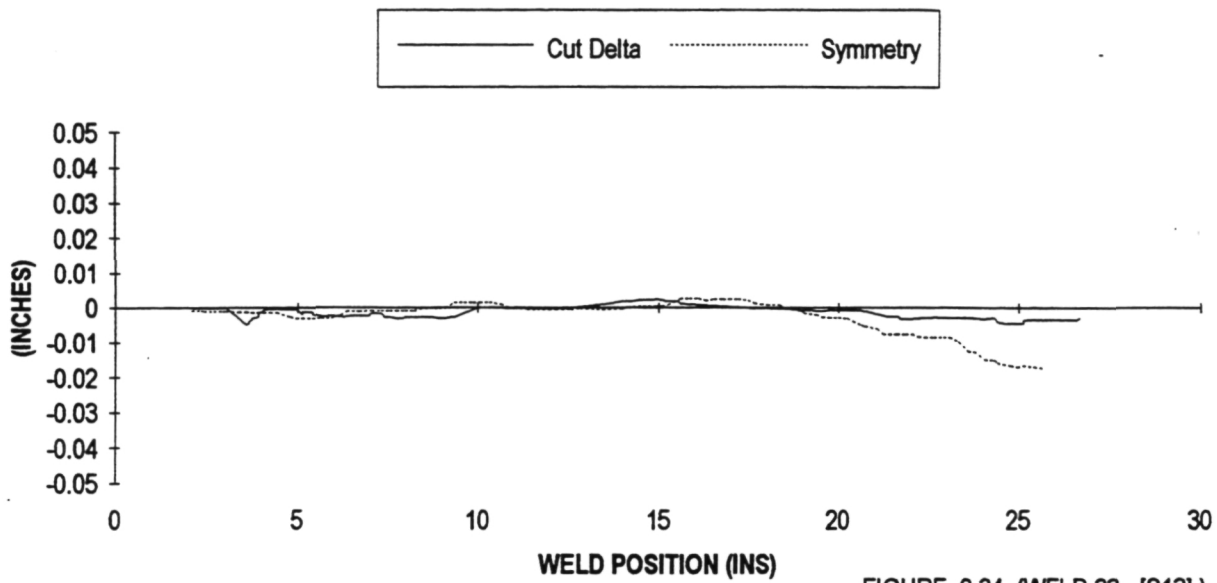


FIGURE 2-24 (WELD 5 [C9])









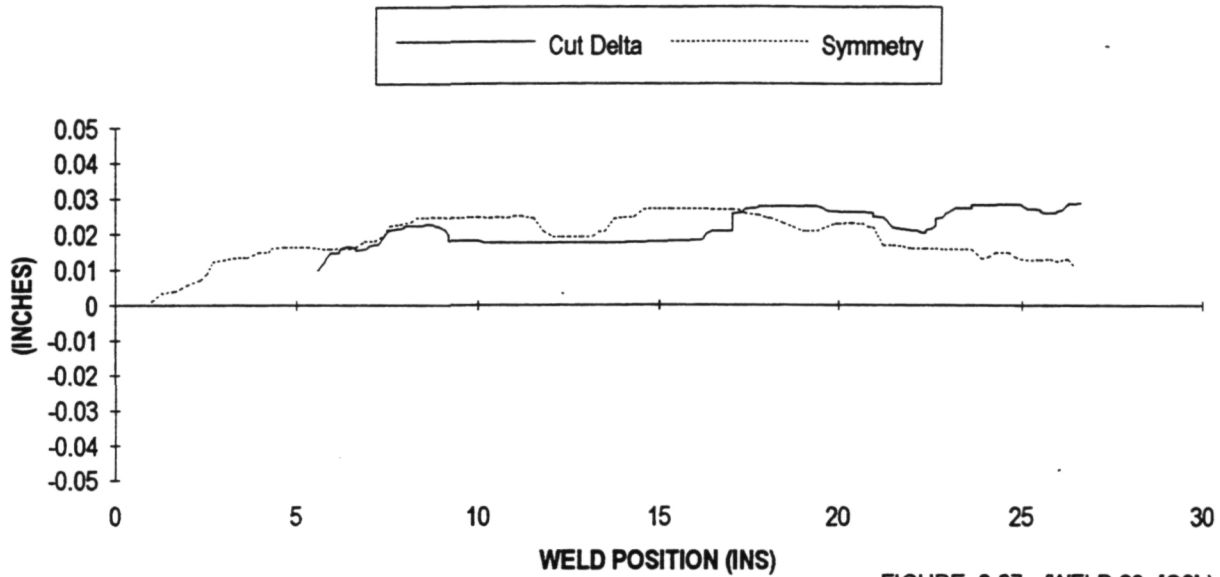


FIGURE 2-37 (WELD 39 [Q3])

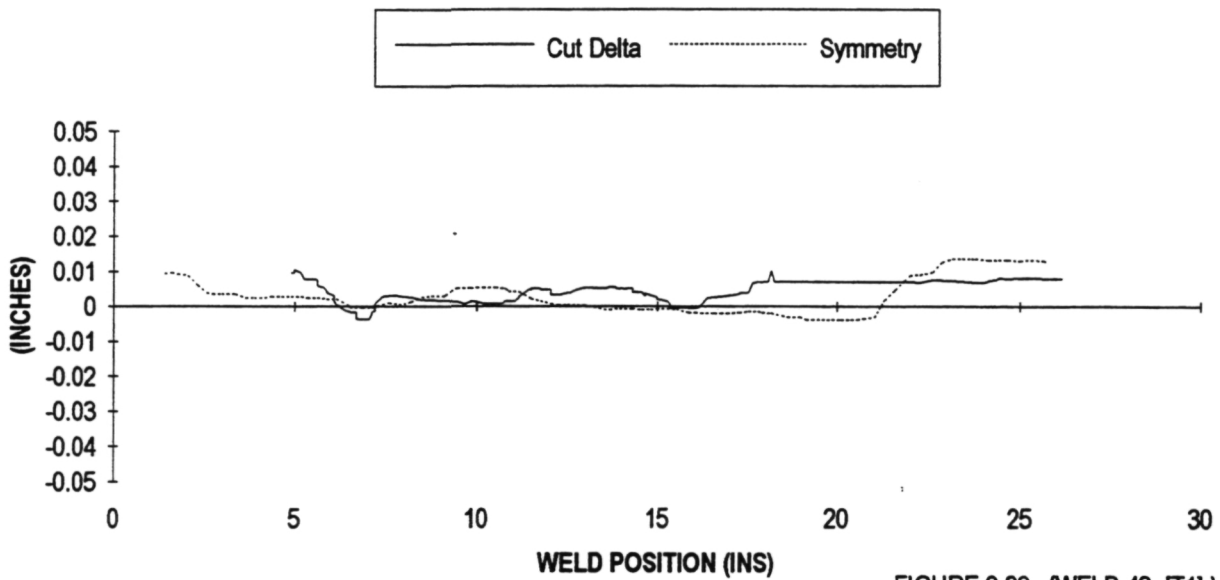


FIGURE 2-38 (WELD 43 [T1])

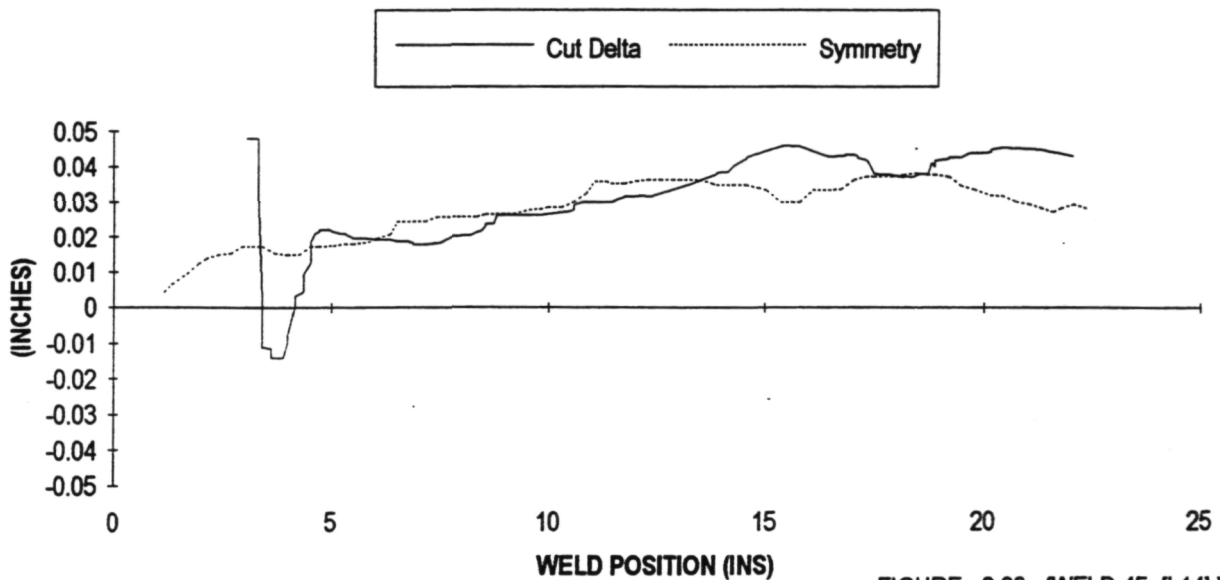


FIGURE 2-39 (WELD 45 [L14])

2.5 Future Enhancements

Several improvements can be made to the Weld Pool Sensor. Synchronizing the shutter with the arc current so that each image will be taken at the same point in the current cycle. This would avoid the possibility of the problem discussed above where the arc intensity fluctuates in the video because the shutter and VPPA rates are different allowing periodic images of the arc as it reverses polarity. The sensor can be redesigned to be smaller allowing for use in tighter places. Also field of view size could be made optional which would allow for a broader range of usage. A fiber optic cable could be adapted to the CCD camera to allow images in very confined areas or close in observations of the arc and weld pool.

Other possible improvements are in the software and include automated shutter speed to cover more easily a broad range of arc intensities. Addition of neural network processing to feature extraction could improve reliability and make the sensor more robust. The sensor could become part of an adaptive real time weld control system.

2.6 Conclusions

This effort to develop a weld pool sensor has had some promising results which will make the weld pool sensor a valuable addition to a sensor suite used for adaptive real time weld control. These results include:

- The most promising results are obviously from the correlation between keyhole symmetry and cut delta. While these do not correlate precisely they are close especially for larger errors. The degree of correlation seen lends the keyhole symmetry to being an integral element in either an adaptive or a null point control scheme for instantaneously controlling torch rotation in order to control weld cuts.
- Torch to keyhole separation correlates fairly well to arc voltage and could be used as part of an adaptive control system.
- The ability to extract bead center from the video is obviously very significant because without this information the best a control system could do would be to keep the torch

center aligned with the seam. If there is no arc skew this will be satisfactory but otherwise a higher quality weld will result if the arc itself is centered on the seam.

Although some refinements should be made to the sensor, mostly in the image processing algorithms, it is evident that the weld pool sensor development has been successful.

3.0 Weld Bead Profile Sensor

A secondary objective in this project was the upgrade of the weld bead profiling sensor software and investigating additional ways to use the data coming from this sensor. Bead measurement accuracy tests were run and the results are discussed in this section.

3.1 Introduction

The profiler is a laser-based surface profiling sensor capable of measuring profiles of a variety of surface types. It has proven especially useful for both preweld fitup inspection of weld parts and postweld inspection of weld beads. For preweld inspection, parameters such as peaking, mismatch and gap are extracted and archived for later display and analysis. For postweld inspection, parameters such as weld bead width, mismatch and crown height are extracted and archived.

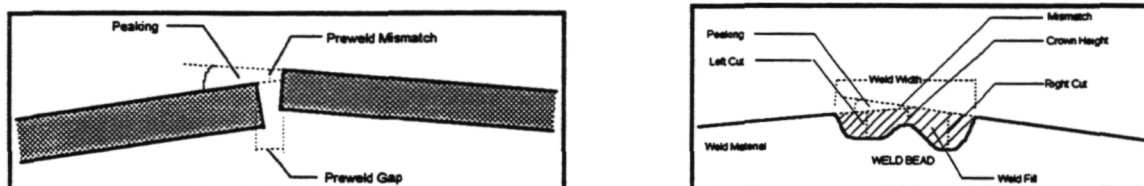


Figure 3-1. Preweld and Postweld parameterization examples

The weld bead profiling sensor (profiler) has undergone many changes in the five years since its inception. Additional capability in the form of dedicated sensor processor development and additional software capability were added to the existing profiler hardware/software design.

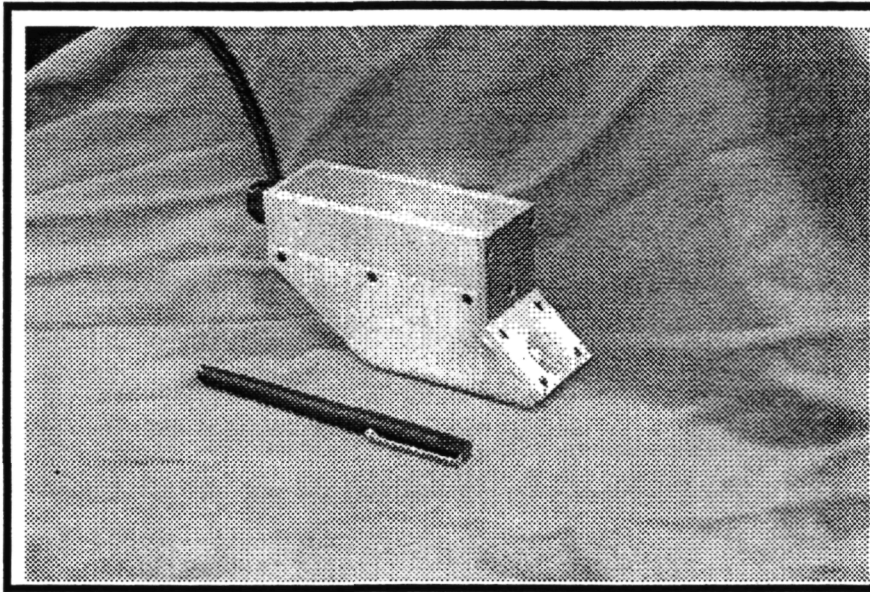
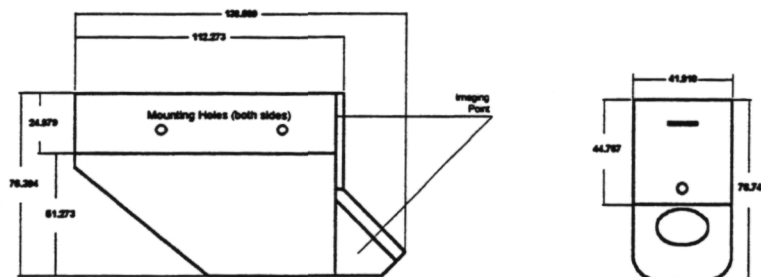


Figure 3-2. Weld Bead Profile Sensor

3.2 Weld Bead Profile Sensor Development

The profiler software was ported from the previously developed system based around an IBM AT system to the system hardware described in Section 5.0. The latest version of the profiler (ARI part number BP1000) was used for all profiling tests under this contract. No changes to the existing profiler design were made.



Dimensions	3.0"(h) x 5.46"(l) x 1.65" (w)
Weight	1.15 lb
Cooling	Air

Figure 3-3. Mechanical Specifications of Profiler.

3.3 Profiling Algorithm Development

All profile extraction algorithms remained the same as were previously developed with NASA and Martin Marietta. All algorithms were implemented on the PCPU hardware described in Section 5 and tested with this hardware.

3.4 Weld Bead Profile Sensor Testing

Profiling measurement accuracy tests were performed using ten selected samples of weld beads, each of different thickness and surface type. Tests were conducted to determine absolute measurement accuracy and repeatability of these measurements. The weld bead features tested were:

1. crown height - maximum distance above parent level line between the parent edges.
2. peaking - angular separation of the left and right parent edges.
3. mismatch - difference in the height of the projected parent material at the center of the weld.
4. left undercut - maximum depth of the weld bead between the crown and the left parent edge.
5. right undercut - maximum depth of the weld bead between the crown and the left parent edge.

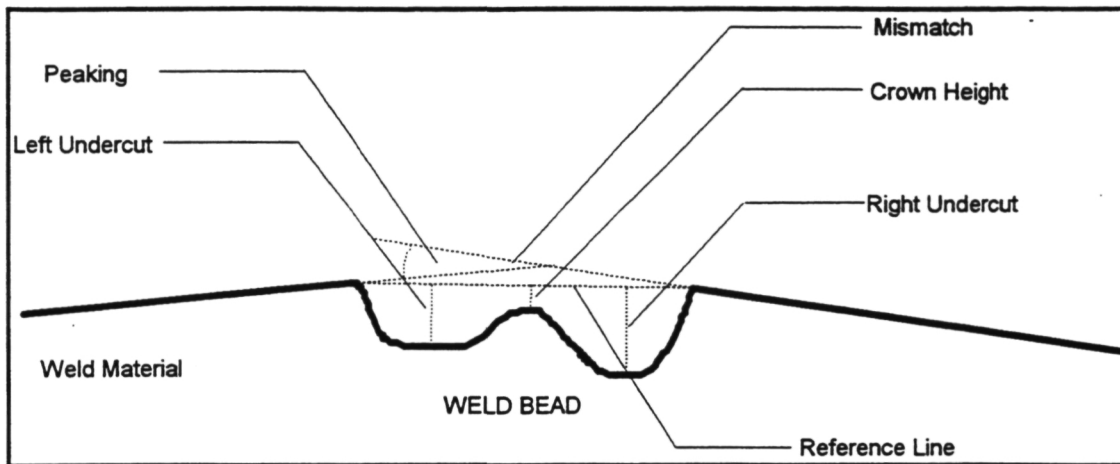


Figure 3-4. Weld Bead Parameters Measured for Test.

3.4.1 Absolute Measurement Error Test

The following table summarizes the results from the absolute measurement error test. Ten samples were profiled and features were extracted using the existing profile processing algorithms. The ten samples were then shadow-graphed to determine the actual parameter measurements of the weld bead. Three different personnel were used to determine the shadowgraph measurements and the results were averaged and used as the actual parameter measurements.

3.4.1 Absolute Measurement Error Test

The following table summarizes the results from the absolute measurement error test. Ten samples were profiled and features were extracted using the existing profile processing algorithms. The ten samples were then shadow-graphed to determine the actual parameter measurements of the weld bead. Three different personnel were used to determine the shadowgraph measurements and the results were averaged and used as the actual parameter measurements.

Table 3-1. Weld Profile Parameterization Absolute Error Results.

Sample #	Measurement Source	Left Cut	Right Cut	Crown	Cut Delta	Mismatch	Peaking
8031013-06	Profiler	0.001	0.003	0.039	-0.002	-0.001	-2.18
	Shadowgraph	0.000	0.000	0.036	0.000	-0.008	-1.19
	Difference	0.001	0.003	0.003	0.002	0.007	0.99
8031438-06	Profiler	0.005	0.002	0.066	0.003	0.053	-12.69
	Shadowgraph	0.000	0.000	0.064	-0.001	0.053	-12.23
	Difference	0.006	0.002	0.002	0.004	0.000	0.46
8031438-18	Profiler	0.003	0.001	0.058	0.002	-0.023	-14.47
	Shadowgraph	0.000	0.000	0.058	0.000	-0.021	-13.36
	Difference	0.004	0.001	0.000	0.002	0.002	0.82
8030904-06	Profiler	0.004	-0.002	0.028	0.006	-0.016	-1.55
	Shadowgraph	0.011	0.000	0.026	0.011	-0.019	-0.78
	Difference	0.007	0.002	0.002	0.005	0.003	0.76
7251514-06	Profiler	0.068	0.050	-0.039	0.019	-0.001	0.34
	Shadowgraph	0.068	0.047	-0.033	0.021	0.001	0.19
	Difference	0.000	0.002	0.006	0.002	0.002	0.15
7251505-18	Profiler	0.072	0.047	-0.033	0.024	0.000	-0.12
	Shadowgraph	0.070	0.044	-0.030	0.026	-0.005	0.07
	Difference	0.002	0.003	0.003	0.002	0.005	0.19
7251448-06	Profiler	0.065	0.049	-0.025	0.016	-0.004	-0.07
	Shadowgraph	0.070	0.049	-0.026	0.021	-0.009	-0.020
	Difference	0.005	0.000	0.001	0.005	0.005	0.13
7251159-12	Profiler	0.042	0.023	-0.012	0.019	0.001	-0.27
	Shadowgraph	0.047	0.026	-0.012	0.021	-0.002	-1.05
	Difference	0.005	0.003	0.000	0.002	0.003	0.77
7241007-06	Profiler	0.005	0.006	0.012	-0.001	-0.036	-1.29
	Shadowgraph	0.003	0.005	0.017	-0.003	-0.027	0.27
	Difference	0.002	0.001	0.005	0.002	0.008	1.56
7241007-18	Profiler	0.010	0.008	0.006	0.002	-0.026	-0.42
	Shadowgraph	0.008	0.010	0.010	-0.002	-0.020	0.12
	Difference	0.002	0.002	0.004	0.004	0.007	0.54
Mean		0.003	0.002	0.003	0.003	0.004	0.64

The accuracy of the sensor improved from the original configuration as shown in the following table which shows average errors in the measurements for all of the profile

parameters. These improvements were predominantly due to the increased frequency of the sensor digitizing hardware. The original configuration used a 10 MHz digitization rate, which yielded approximately 500 samples per line of video. With the updated hardware, the data was digitized at 14.3 MHz, for a resolution of greater than 780 samples per line of video. This increased resolution provided more data points with which to calculate the profile centerpoint in the video, thus yielding an increased resolution.

Table 3-2. Weld Bead Parameter Measurement Resolution Comparison.

Profiler Version	Crown Height	Left Cut	Right Cut	Mismatch	Peaking
Original Profiler	0.006	0.005	0.006	0.004	1.77
Upgraded Profiler	0.003	0.003	0.002	0.004	0.64

3.4.2 Repeatability Test

A repeatability test was performed on a randomly selected sample from the ten samples used in the absolute measurement test. The sample was placed in the sensor's field-of-view and a measurement was taken. This test was performed 10 times and the mean and standard deviation of the results were tabulated. Table 3-3 gives the results of this test. In summary, the repeatability of depth measurements was less than 0.002" for all parameters. The peaking measurement repeatability was 0.22 degrees.

Table 3-3. Weld Bead Profile Parameter Repeatability Test Results

x	left	right	crown	mm	delta	fill	width	peaking
3.727	0.068	0.050	-0.038	-0.003	0.019	-0.058	0.048	-0.100
9.573	0.068	0.050	-0.040	0.000	0.018	-0.068	0.490	0.298
17.315	0.067	0.051	-0.038	0.000	0.016	-0.149	0.488	-0.124
24.440	0.068	0.050	-0.038	0.000	0.018	-0.055	0.490	0.123
31.198	0.068	0.050	-0.039	0.001	0.018	-0.074	0.488	0.328
36.518	0.067	0.048	-0.036	0.003	0.019	0.032	0.487	0.042
43.075	0.067	0.049	-0.038	-0.002	0.018	-0.095	0.491	-0.076
49.969	0.068	0.049	-0.038	0.002	0.019	-0.028	0.493	0.176
56.667	0.068	0.049	-0.039	0.002	0.018	-0.096	0.490	0.554
62.789	0.067	0.050	-0.038	0.002	0.018	-0.102	0.494	0.307
Mean	0.068	0.049	-0.038	0.001	0.018	-0.069	0.490	0.153
St. Dev.	0.000	0.001	0.001	0.002	0.001	0.048	0.003	0.222

3.5 Future Enhancements

No future enhancements are expected to the profiling sensor. However, better laser cooling hardware may be necessary to extend the life of the laser in the sensor. The system software must also be configured to allow maximum flexibility for an operator, such as setup and configuration options and user display screens.

3.6 Conclusions

The profiler has reached a point of maturity at which it is very useful for application to MAF/ET data acquisition support. The hardware is very reliable and measurements are repeatable. The modular design of the sensor allows expedience of repairs and servicing, which fits very well into a commercial environment.

4.0 Stereo Seam Tracking Sensor

4.1 Introduction

The stereo seam tracking sensor is a stereo imaging vision sensor which uses innovative illumination techniques coupled with gray-scale processing on a stereo pair of images to deduce seam location, thus yielding three-dimensional position information from a single video frame of information. High-powered pulsed lasers are used for illumination of the seam. Coupled with the seam measuring capability is a view of the leading edge of the torch, giving the operator torch visibility during the weld. The torch view of the sensor gives the operator remote viewing capability of the leading edge of the keyhole which can be used for manual seam tracking (first or second pass) and weld wire placement.

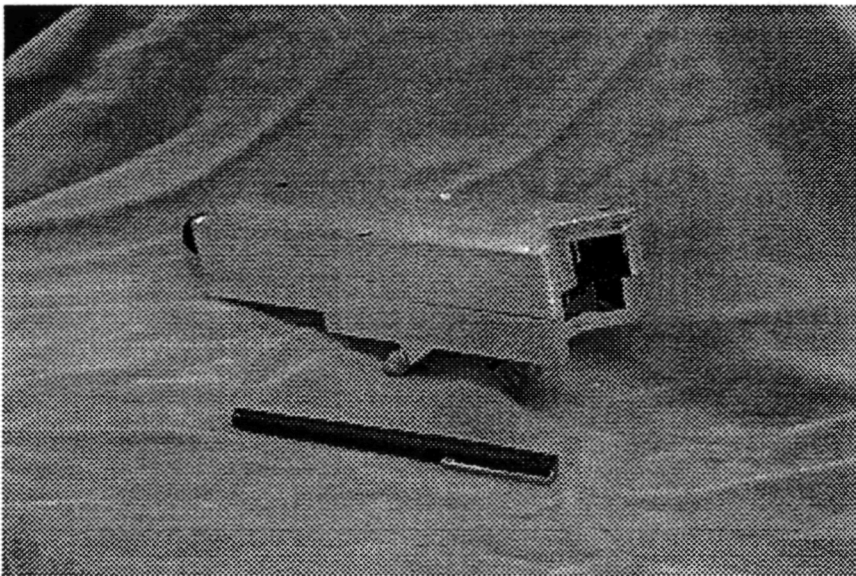


Figure 4-1. Stereo Seam Tracking Sensor

The video of the ST1001 outputs a split screen image: the top half of the image shows the "left eye" and "right eye" view of the stereo pair. The bottom half of the image gives a view of the leading edge of the torch.

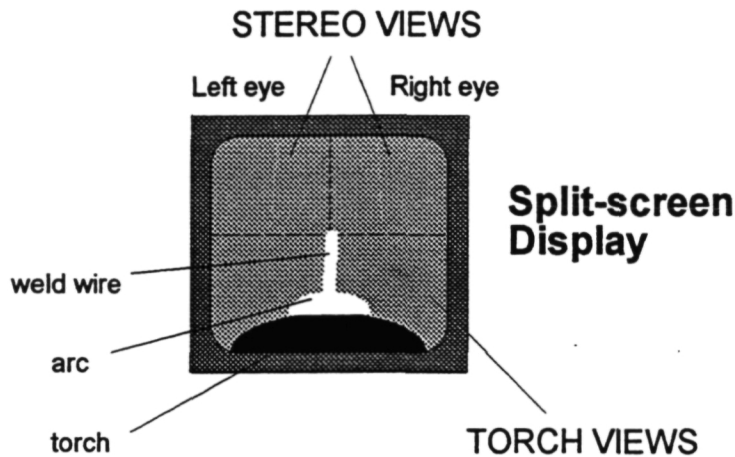


Figure 4-2. Seam Tracker Video Description

It was found that the keyhole view imagery could be used most efficiently for operator viewing and teleoperating of functions such as wire entry position and first and second pass seam tracking. The stereo view gives imagery sufficient enough to locate the seam position.

4.2 Stereo Seam Tracking Sensor Development

The limitations of the existing seam tracker design were investigated and solutions to these problems were designed, implemented and tested. The following sections summarize the findings.

4.2.1 Existing Stereo Seam Tracker Description

The existing version of the stereo seam tracker was found to have several limitations subsequent to extensive testing by NASA and MMC personnel (under separate contracts). This was a first-version of the sensor which was a brassboard model and served to demonstrate the utility of stereo seam tracking capability. The following areas were found to be in need of improvement:

1. Mounting distance from torch
2. Physical packaging
3. Imaging characteristics
4. Illumination lasers

In tests conducted at MAF for Martin Marietta, the physical separation of the sensor from the torch proved to be one design flaw which needed correction. The existing version of the seam tracker was placed at a minimum of 8.0 inches from the centerline of the torch. This separation contributed to tracking error caused by unaccountable tool motion of the welding fixture. The tracking error was, at a minimum, the maximum tool motion over the sensor-to-torch separation distance of 8 inches.

The 8 inch sensor separation was necessary in the existing design because:

1. The physical size of sensor did not allow imaging in close proximity to the torch since tooling clamps were too close together. The existing sensor design had a housing width of 3.25 inches.
2. The wire manipulator occupied the area immediately above the torch, so no room was available for the sensor.
3. Illumination lasers were continuous wave and were not ideally suited for arc light rejection for minimum optical noise in the image, so the arc light "clouded" the image of the seam if placed too close to the torch.

The sensor-to-torch separation also required a larger field-of-view to accommodate all possible seam locations relative to the sensor, thereby reducing resolution. Ideally, the closer the sensor is to the torch, the smaller field-of-view is necessary to place the seam in the imaging area of the sensor.

In order to decrease the error in seam tracking, the most significant improvement to be performed was to decrease the sensor-to-torch distance. All of the design limitations as outlined above were investigated and adequate solutions were found.

4.2.2 Advanced Seam Tracker Development

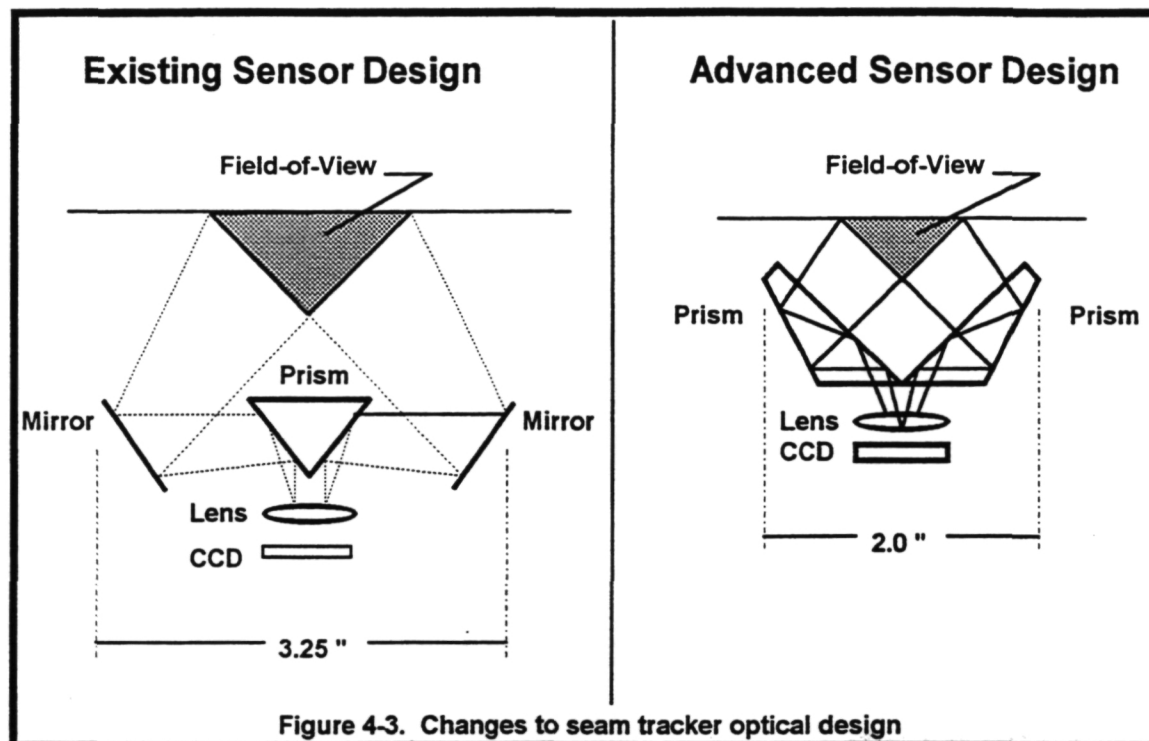
In order to eliminate the limitations found on the existing version of the stereo seam tracker (Section 4.2.1), a new version of the seam tracker was developed. Each item mentioned above was addressed and solved under this contract. The design goals included:

- modular design for minimum maintenance and service
- smaller, more compact design to fit into small areas
- increased functionality
- industrially hardened design
- computer controlled sensor

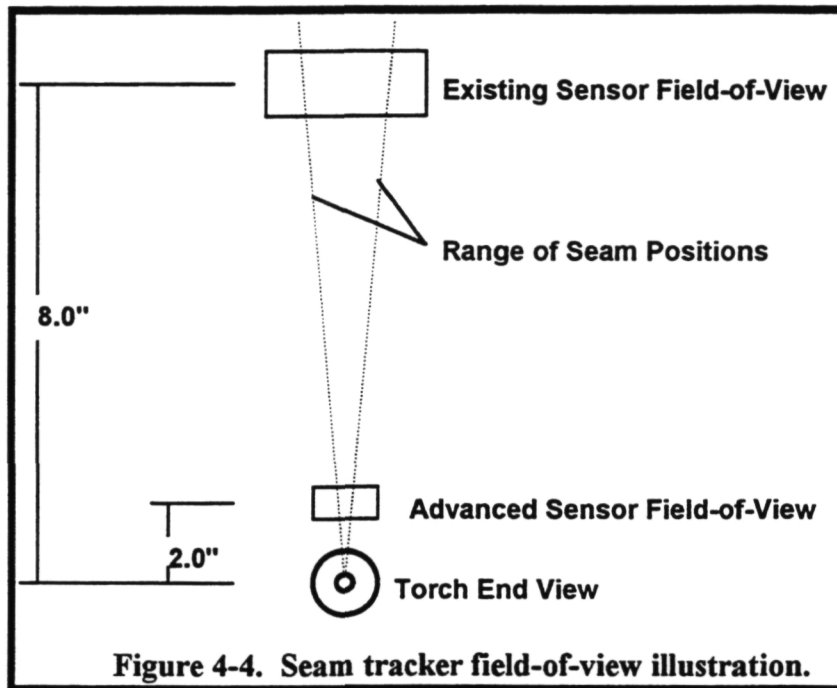
The first design modification performed involved converting the laser illumination from CW to pulsed lasers, which would give better arc light noise rejection capability to the sensor. By minimizing the arc light noise, the sensor can be placed closer to the torch without interference.

The lasers used are identical to the pulsed lasers used in the weld bead profiler, the Laser Diode, Inc. LD-215C, which is a 180 Watt peak power class IIb laser device. This laser was found to have sufficient power for illumination of the seam plus the added capability of laser pulsing to deliver more light to the area of interest in a short amount of time. This pulsing of the illumination coupled with a shuttered CCD imager allows integration of 100% of the laser light with a significant reduction in integrated arc light. For example, using a CW laser requires that the CCD integrate for a full field time (1/60 second) to obtain proper illumination. Since the CCD is integrating for the full time, the arc light is also integrated during this period. However, by using the pulsed laser/shuttered CCD arrangement, proper illumination can be integrated in less than 1/10,000 second (i.e. the laser "dumps" all of its light on the area of interest in this period), so if the CCD is shuttered at 1/10,000 second, the apparent arc light is reduced by the ratio of a full field time (1/60 sec) and the shutter speed (1/10,000 sec), or 167 times. In other words, use of the pulsed laser reduces the arc brightness by up to 167 times with no reduction in illuminated image brightness.

Once the laser illumination design was performed, the packaging of the sensor was redesigned to allow imaging in closer proximity to the torch. The advanced sensor utilized prisms exclusively for the imaging system, rather than moveable mirrors as in the existing design. This allows for a more rigid structure which not adjustable and will not vibrate loose. The packaging also reduced the overall sensor width from 3.5 inches to 2.25 inches, which would allow use in much tighter spaces.

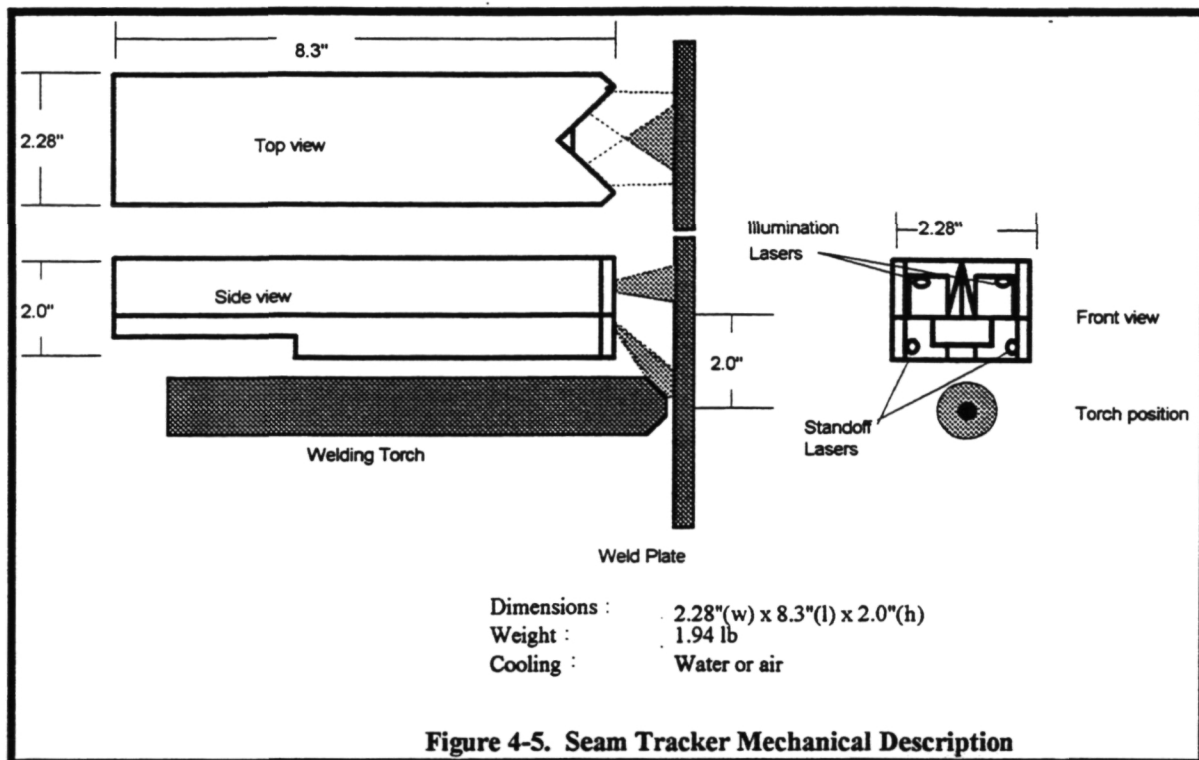


The field-of-view of the sensor was also decreased from approximately 2.0 inches to 1.0 inch a result of the sensor repackaging. However, this does not inhibit sensor performance since a wider field of view is not necessary to image seams when the sensor is in close proximity to the torch. The existing design required a wider field-of-view to accommodate varying seam positions and angles because of the greater sensor-to-torch separation distance, as illustrated in Figure 4-4.



In addition to the above enhancements to the seam tracker design, the sensor was equipped with water or air cooling, and computer-controlled laser brightness and image contrast capability.

During the design of the advanced tracker, it was determined that additional capability to image the leading edge of the keyhole would enhance the utility of the seam tracking sensor. Through this view, imagery of the seam entering the arc (either first or second pass) would be available for operator viewing or teleoperation. Future software enhancements will utilize this view for additional computer control capability. The weld wire as it enters the arc is also visible from this view, allowing operator remote control of the wire entry position. Algorithms to detect the wire position have not been developed.



4.3 Seam Finding Algorithm Development - First Pass Tracking

Software from the existing seam tracking image processing software was ported to the hardware described in Section 5. Changes were made, as necessary, to maximize the setup flexibility for application to many different surface finishes and seam configurations.

The processing algorithms are laid out with a multistep arrangement for maximum flexibility in seam point extraction. Each step can be customized through a sensor setup file for a specific application. The steps required for proper seam identification consist of:

1. Setup sensor specifics, such as laser brightness, shutter control, laser select, etc.
2. Image preprocessing
3. Signal extraction
4. Signal conditioning
5. Correlation (not fully implemented)
6. Post correlation signal conditioning
7. Peak finding
8. Window repositioning

Each of the steps are discussed in more detail in the sections to follow.

4.3.1 Sensor setup

The sensor setup options allow setting of things such as shutter control, laser brightness, laser select, etc. to control illumination and image quality. Certain illumination types work better for certain weld joints.

4.3.2 Image Preprocessing

The image preprocessing step is required for any processing on the 2-D image of the sensor. Functions might include FFT processing, LUT processing, Hough transforms, histogram equalization, etc. which would enhance the image for further processing and signal extraction.

4.3.3 Signal extraction algorithms

The signal extraction step processes the 2-D image and reduces it down to a 1-D signal, representative of the seam. Some functions include line detection, profiling, column averaging, etc. The data is then passed on to the signal conditioning step.

4.3.4 Signal conditioning

The signal conditioning step is required to perform certain operations on the 1-D data. Sample algorithms include smoothing, slant removal, scatter, slope, rescaling or normalization, median filtering, or others as they are defined. As it is now, up to 5 conditioning passes can be performed before going to the next step in the algorithm.

4.3.5 1-D correlation

The 1-D correlation is available for use in template matching, or hard-to-find seams. The implementation of this function is incomplete.

4.3.6 Post correlation signal conditioning

After the correlation step, if used, another signal conditioning step is executed. It is exactly like that described in section 4.3.4.

4.3.7 Peak finding

The peak finder is what actually locates the desired signal in the data. It will find one peak or all available peaks, as specified by the operator. Several options are available for peak finding:

1. Find single large peak passing tests. This looks for one peak in the signal which must pass all of the signal-to-noise, peak-to-sidelobe ratio, signal strength and width tests before passing.
2. Find outside peaks. This looks for the outermost peaks on the left and right side of the window. This is useful for 2nd pass seam finding or where wide joints might be found.
3. Get best candidate peak. This looks at all available peaks and picks the one which best matches the extrapolated seam location from past points. This one could be very dangerous if it gets off on the wrong peak, so has not been fully tested. Extrapolation is done only on verified data from the host.

This algorithm needs both eye views of data to calculate the seam position. If one of the two eye views fail to yield a valid signal, standoff measurement must be made to get accurate seam position. The standoff can be determined one of three ways, which are arranged in order of priority:

1. Previous validated seam standoff, if last valid point was within 0.25" from current position,
2. Profile standoff measurement at current position,
3. Tracker standoff laser measurement at current position.

If both eye views fail to yield a valid signal, then no seam was found.

4.3.8 Window repositioning

Window repositioning options are available as to how the window changes size or position in response to the seam finding algorithm. These allow shrinking of the active window once the seam position is identified or growing of the window to reacquire the seam in the event that the seam was lost.

4.4 Seam Finding Algorithm Development - Second Pass Tracking

For second pass tracking, the keyhole view of the sensor would be used. Software algorithms for extraction of second pass seam point acquisition have not been developed. Advanced concepts utilizing neural network capability may be necessary to predictably extract the second pass seam information. As a minimum, the keyhole view of the sensor will give an operator remote viewing capability in the area at the leading edge of the torch, allowing manual monitoring of the wire entry position and tracking.

4.5 Stereo Seam Tracking Sensor Testing

Tests on the stereo seam tracker's overall seam position measurement accuracy were performed on 12 of the 15 panels prepared by Martin Marietta for past ET-type seam tracking tests. These plates represent most of the seams which are to be expected in all MAF applications. The second pass tracking accuracy was not tested. During the test, tool motion was detected in all of the runs and is evident by the characteristic shape of the data which was consistent in each run. Because of the tool motion, measurement accuracy determination was done by assessing the distance of a seam point from the linear fit of a

segment of each run centered on that point. This was done for each point in a run. Absolute seam point measurement accuracy could not be determined with the setup used, but seam location variability can be calculated.

In the twelve runs, consistent seam point measurement was demonstrated for all of the surfaces tested. The only plate which showed a tracking problem was plate #5 which had a wide gap toward the end of the plate. The tracker followed the center of the gap, but since the gap center points yielded a curved shape, the verification algorithm threw out these points. Modifications to the verification algorithm could have allowed the acceptance of these points and will be considered in the future after realistic limits of gap extremes are defined.

Figure 4-6 shows a summary bar graph of the average absolute error found using the above technique. Plate #5 showed the worst average Y error and was measured to be 0.0051". The lowest average absolute error was found with plates #14 and #15, both which turned out to be 0.0013". The Z error for all plates was always less than 0.0031", which is low enough to yield good Y measurement accuracies when only one half of the stereo pair can be used to determine seam position.

Figures 4-7 to 4-18 show typical runs for each of the plates tested. Obvious from the plots is the system's capability to reject tacks.

One other area which the new seam tracker will improve tracking capability over the previous version is its closer proximity to the torch. In the recent MAF implementation effort for Martin Marietta, tool motion was a contributing factor to the inability of the system to accurately track the joint. While seam point identification worked very well, the system could not close the loop because of unmeasured motion between the time the seam point was found and when the torch had to react to it. In the simplest case, measurement error is equal to the amount of tool motion over the distance of 8 inches (the previous distance between the sensor and the torch). This tool motion introduces another problem in tracking which is verification. To the verification

Figure 4-6. Seamtracker Test Summary

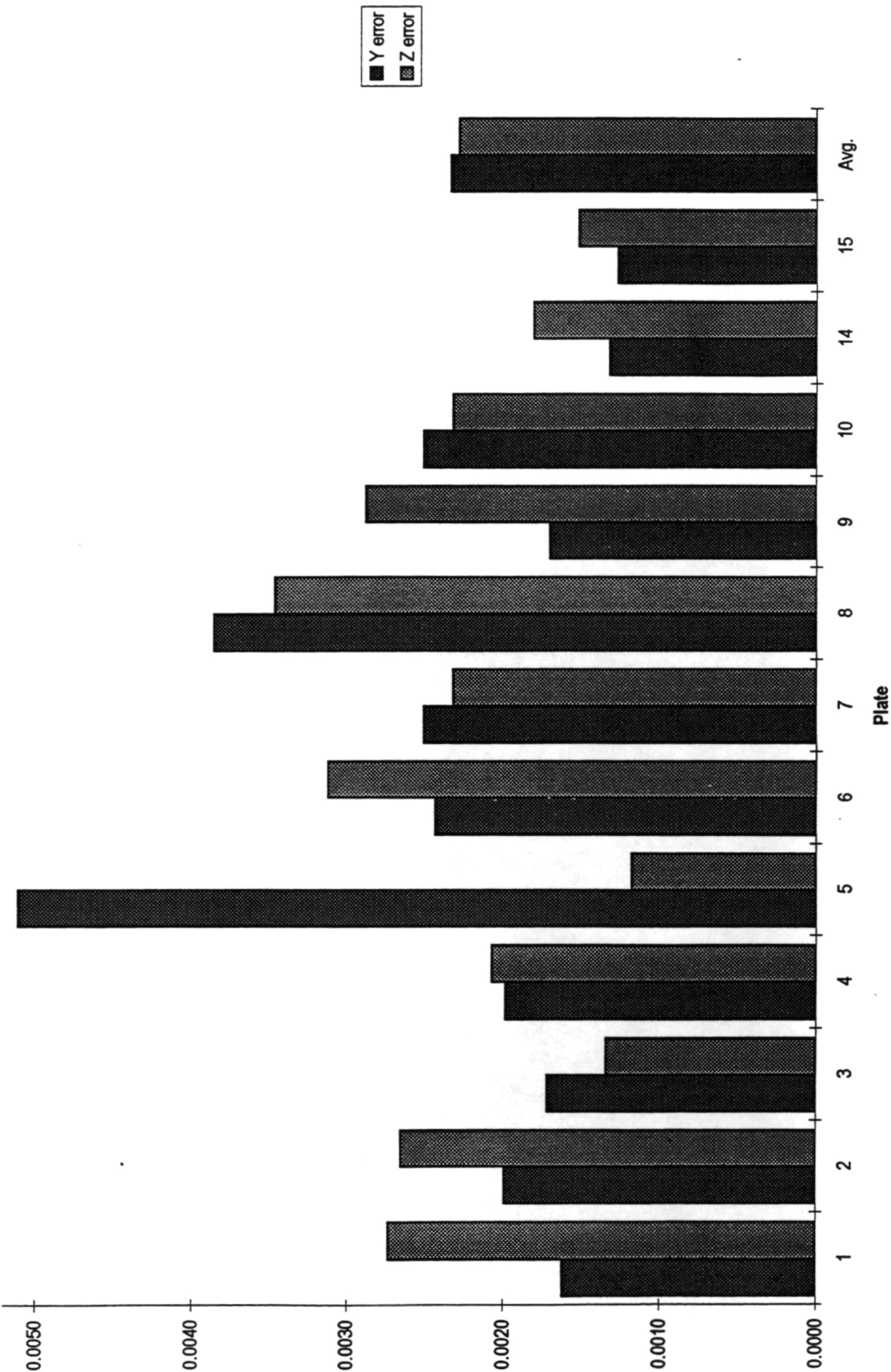


Figure 4-7 Plate 1 Y data vs. line fit

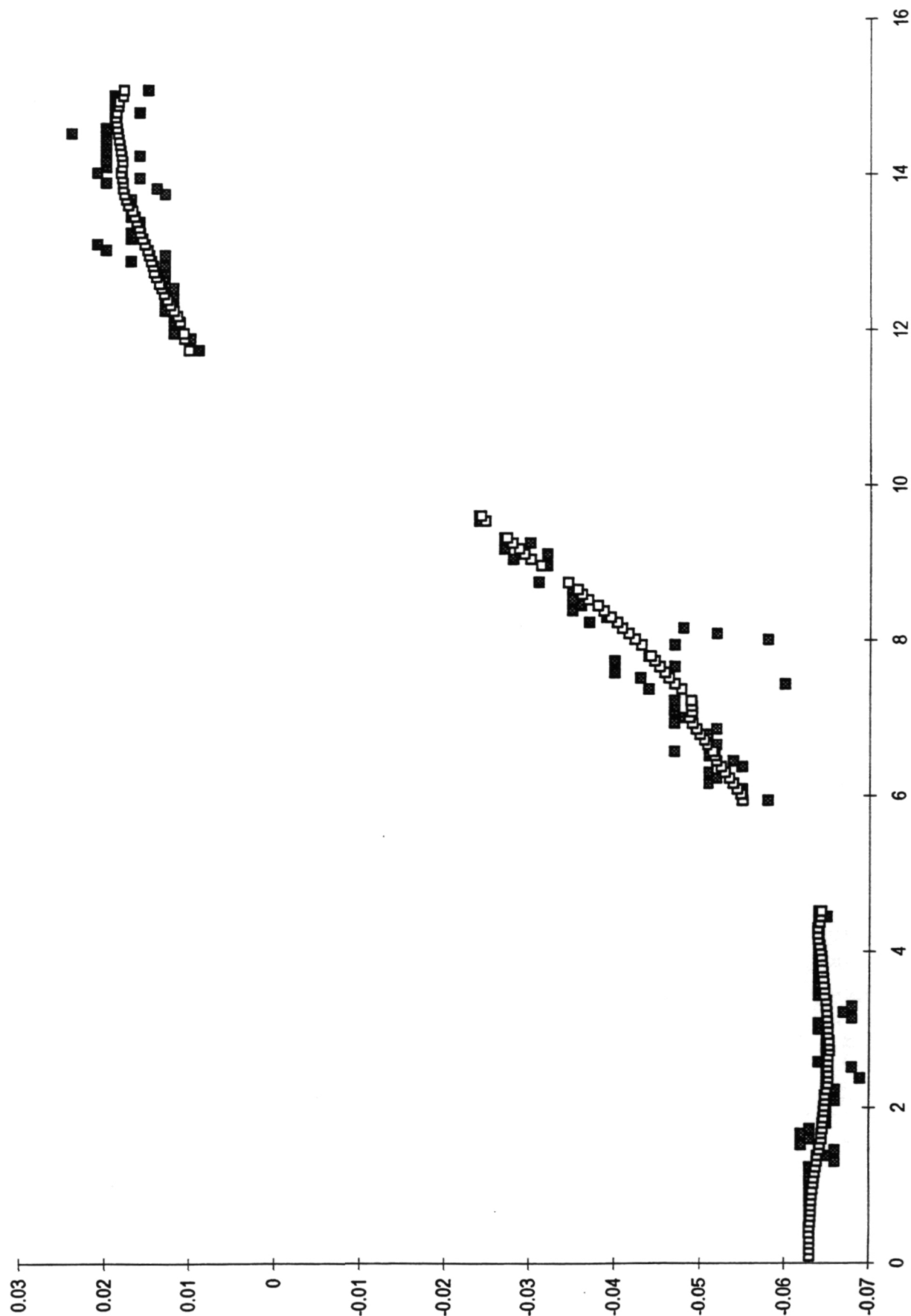


Figure 4-8. Plate 2 Y data vs. line fit

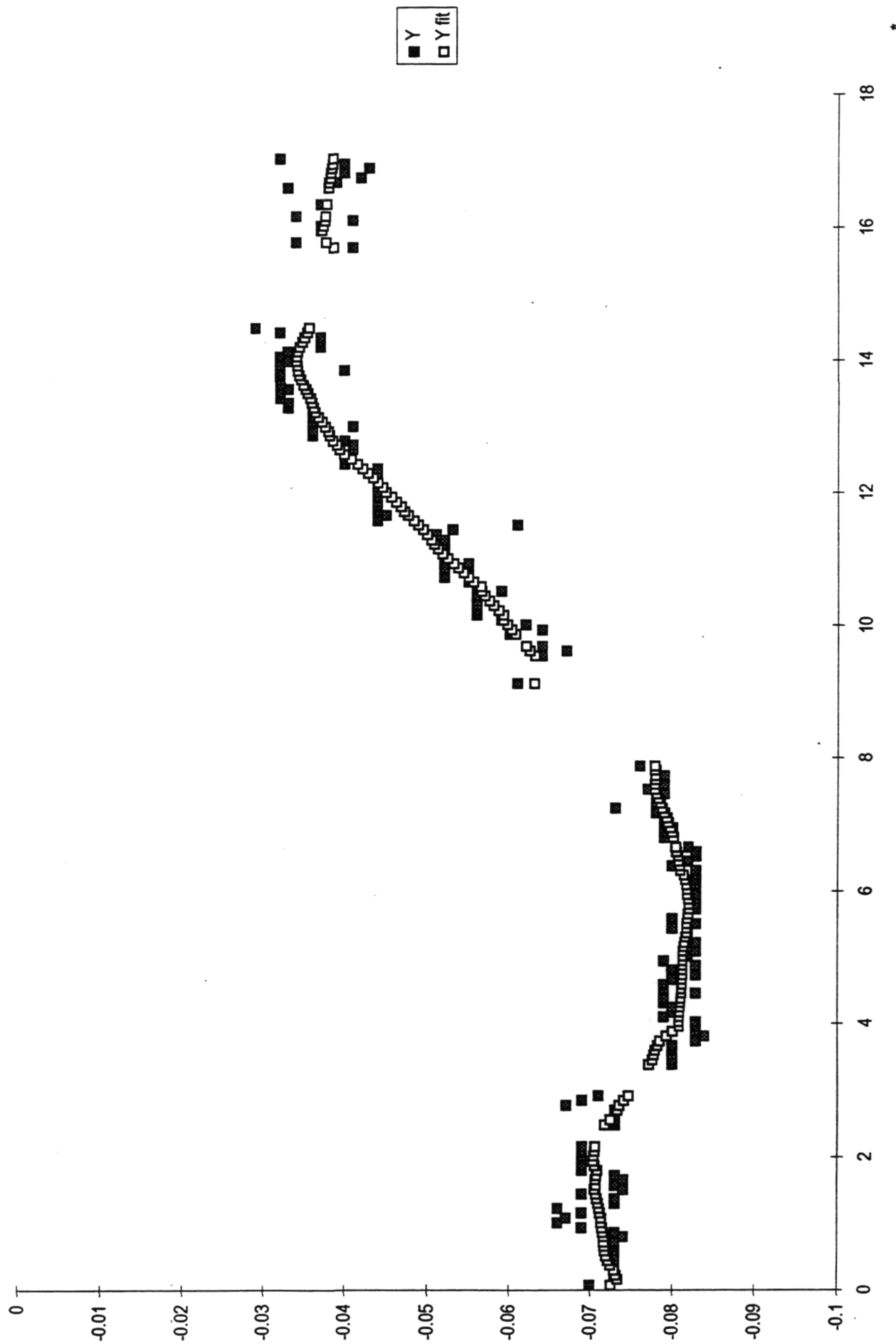


Figure 4-9. Plate 3 Y data vs. line fit

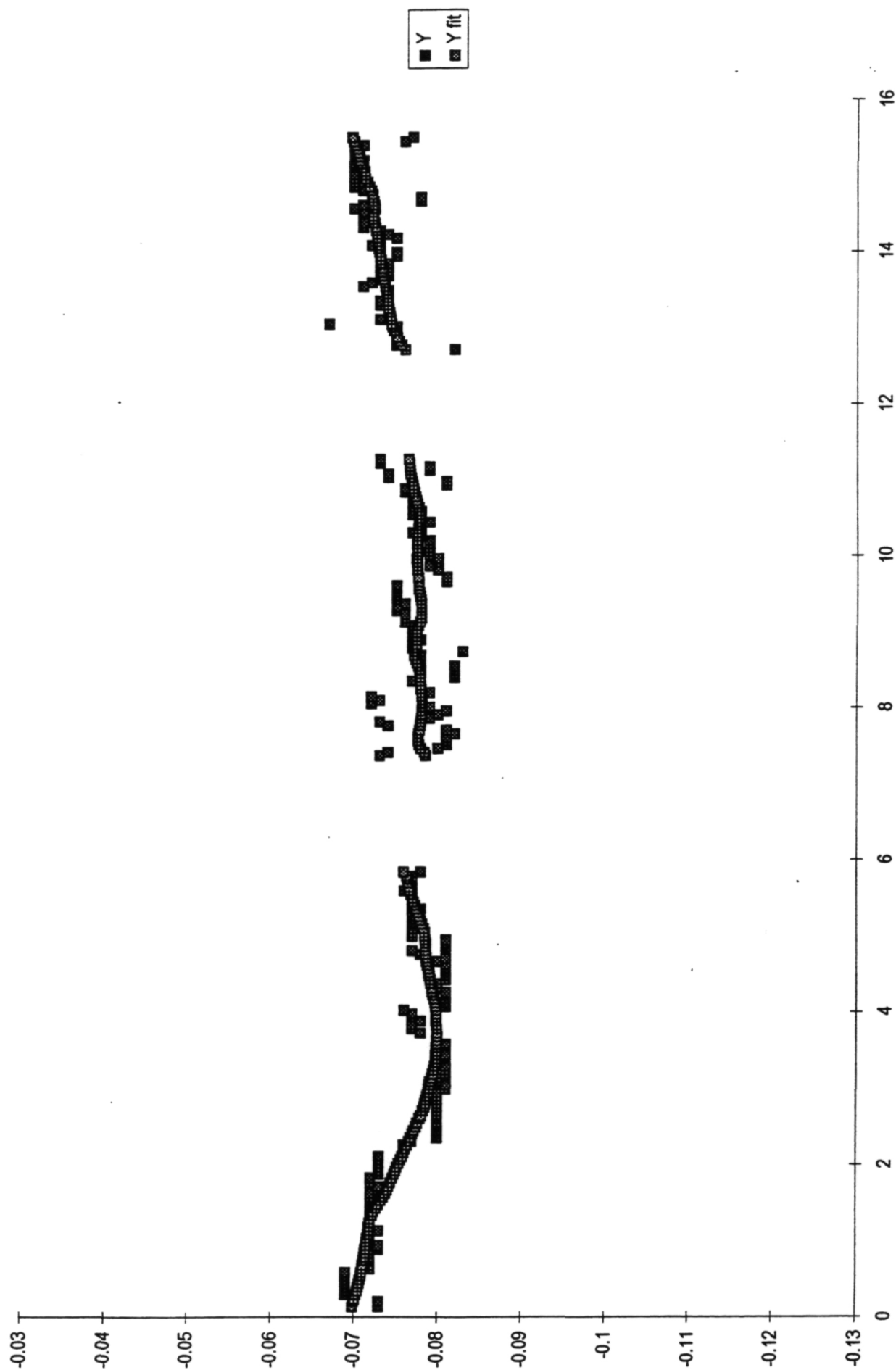


Figure 4-10. Plate 4 Y data vs. line fit

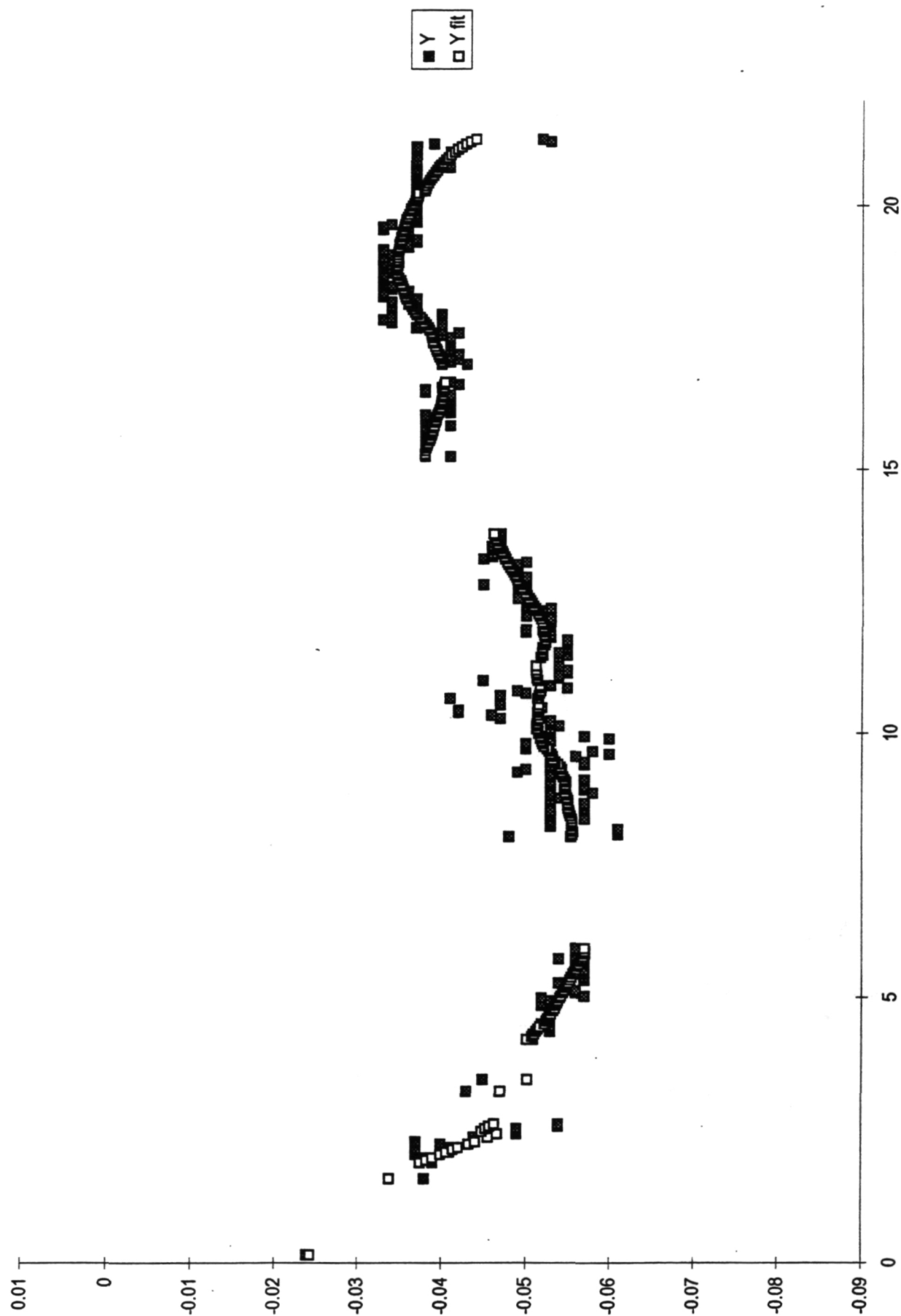


Figure 4-11. Plate 5 Y data vs. line fit

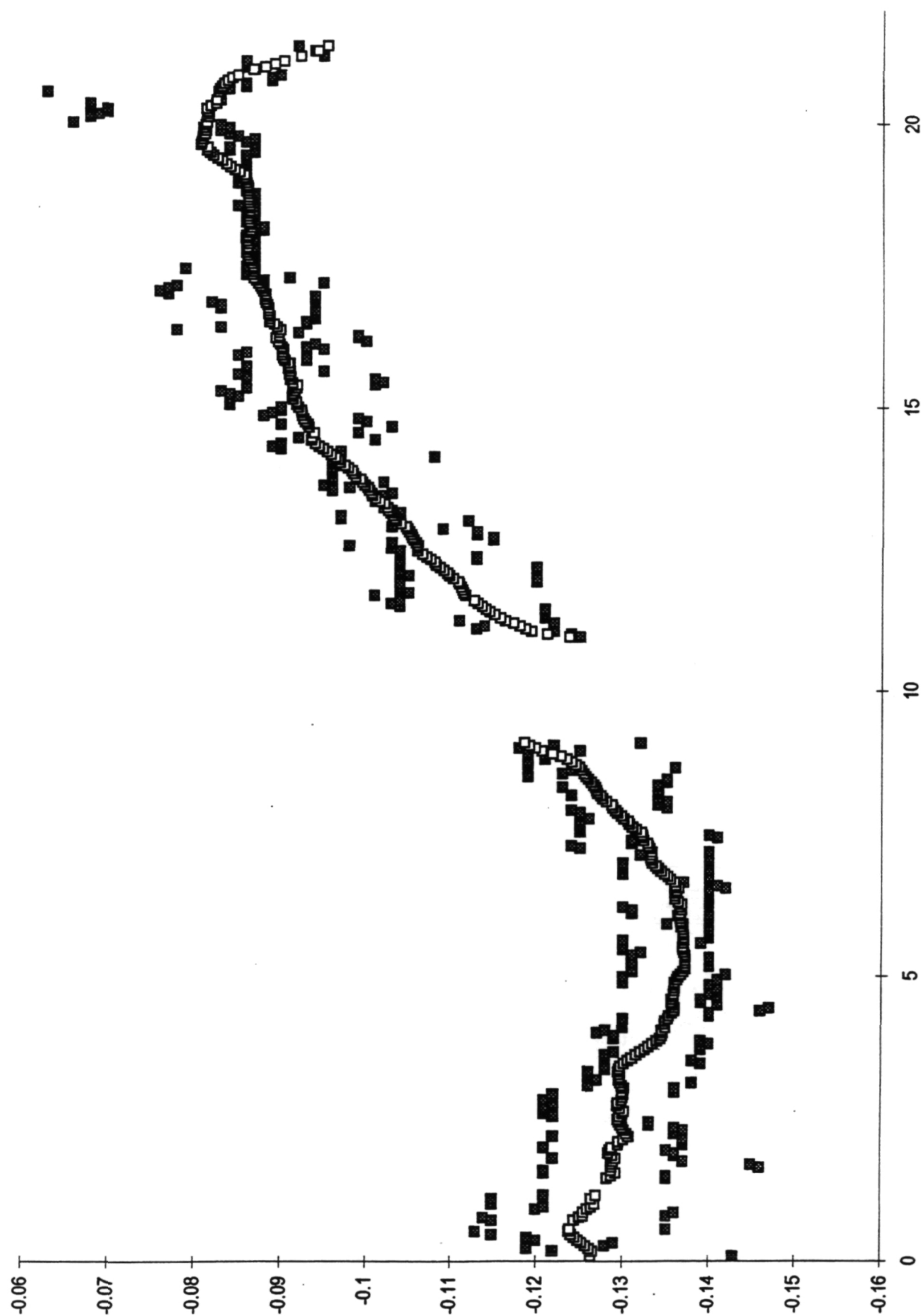


Figure 4-12. Plate 6 Y data vs. line fit

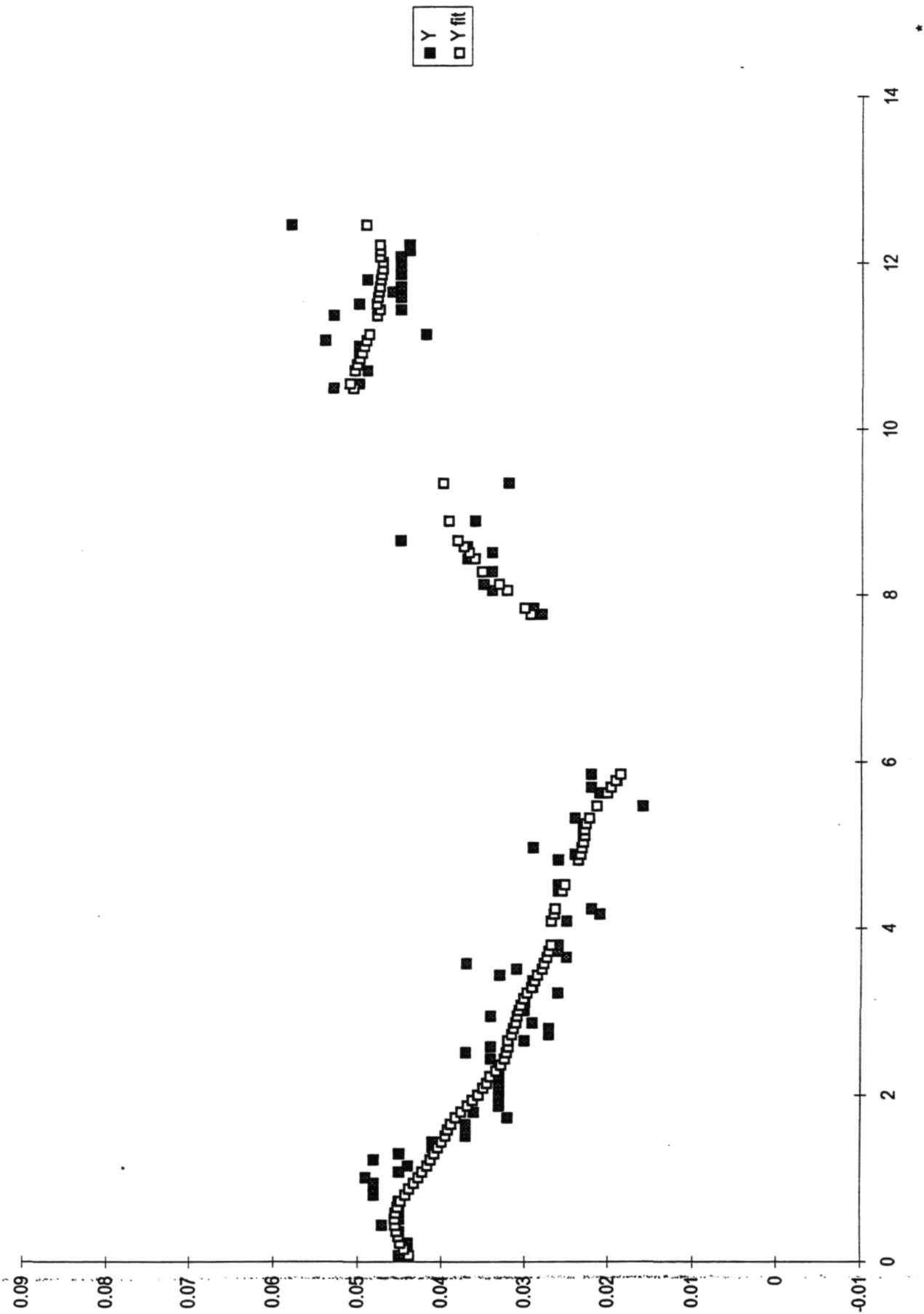


Figure 4-13. Plate 7 Y data vs. line fit

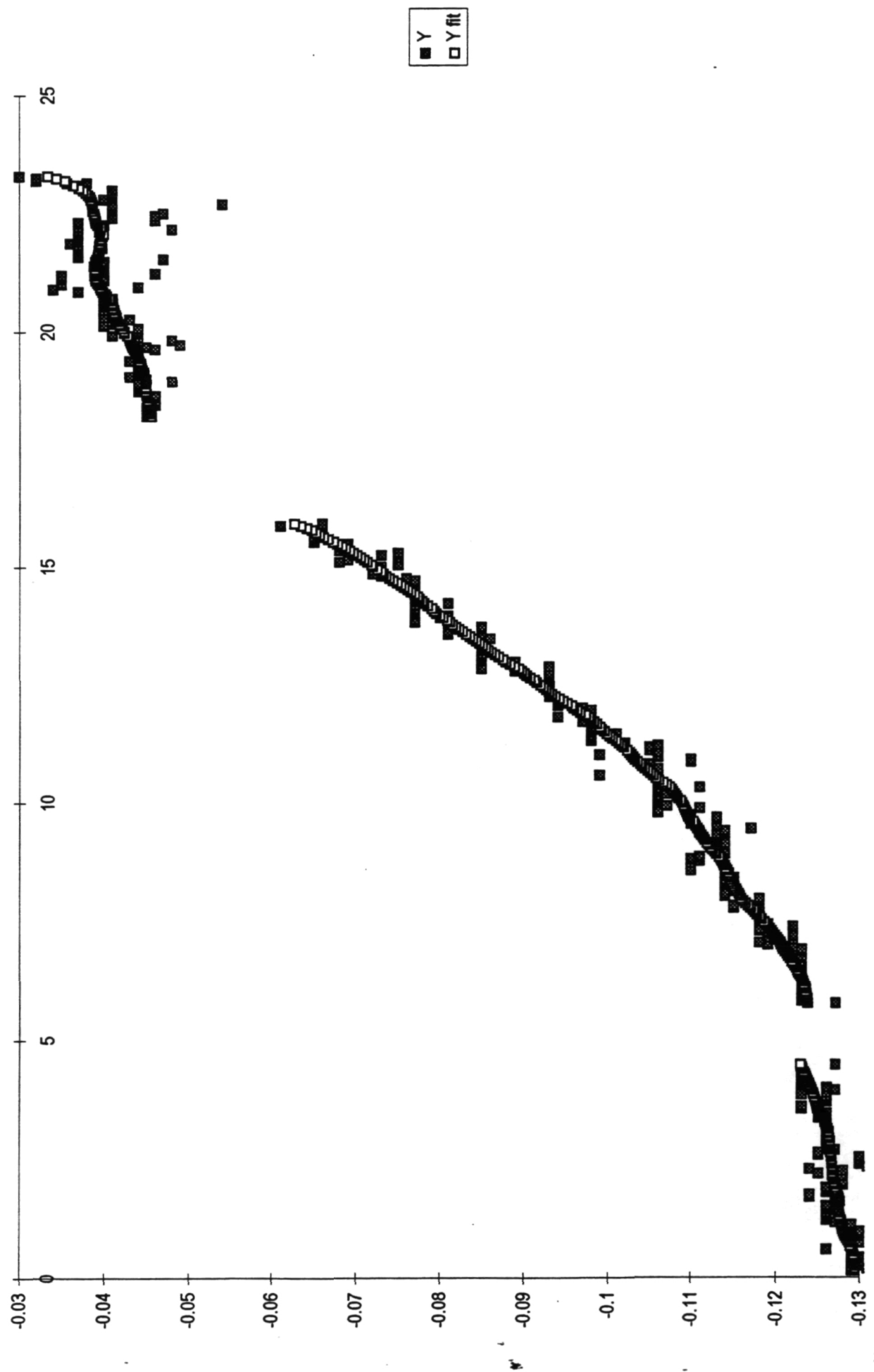


Figure 4-14. Plate 14 Y data vs. line fit

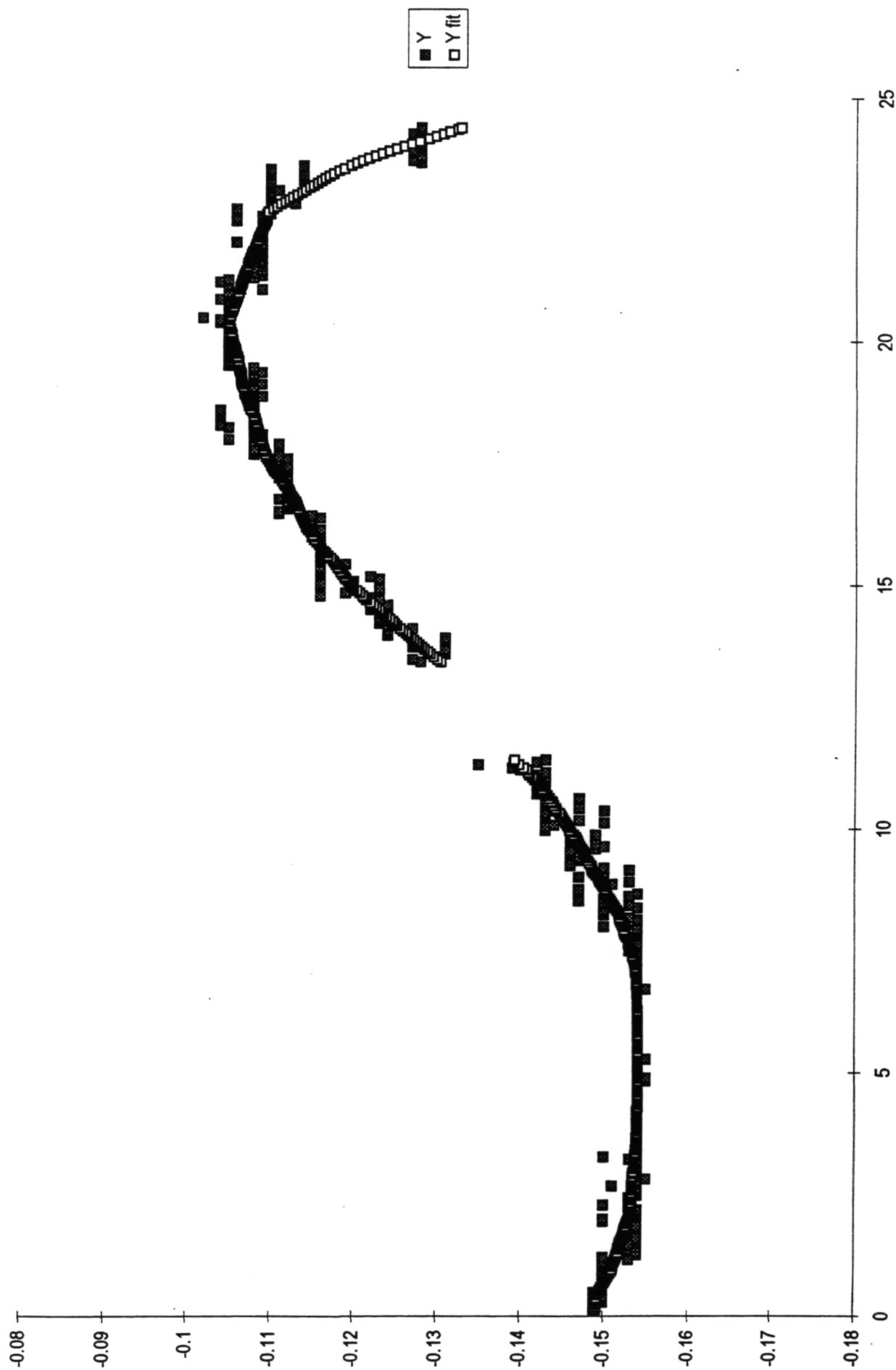


Figure 4-15. Plate 7 Y data vs. line fit

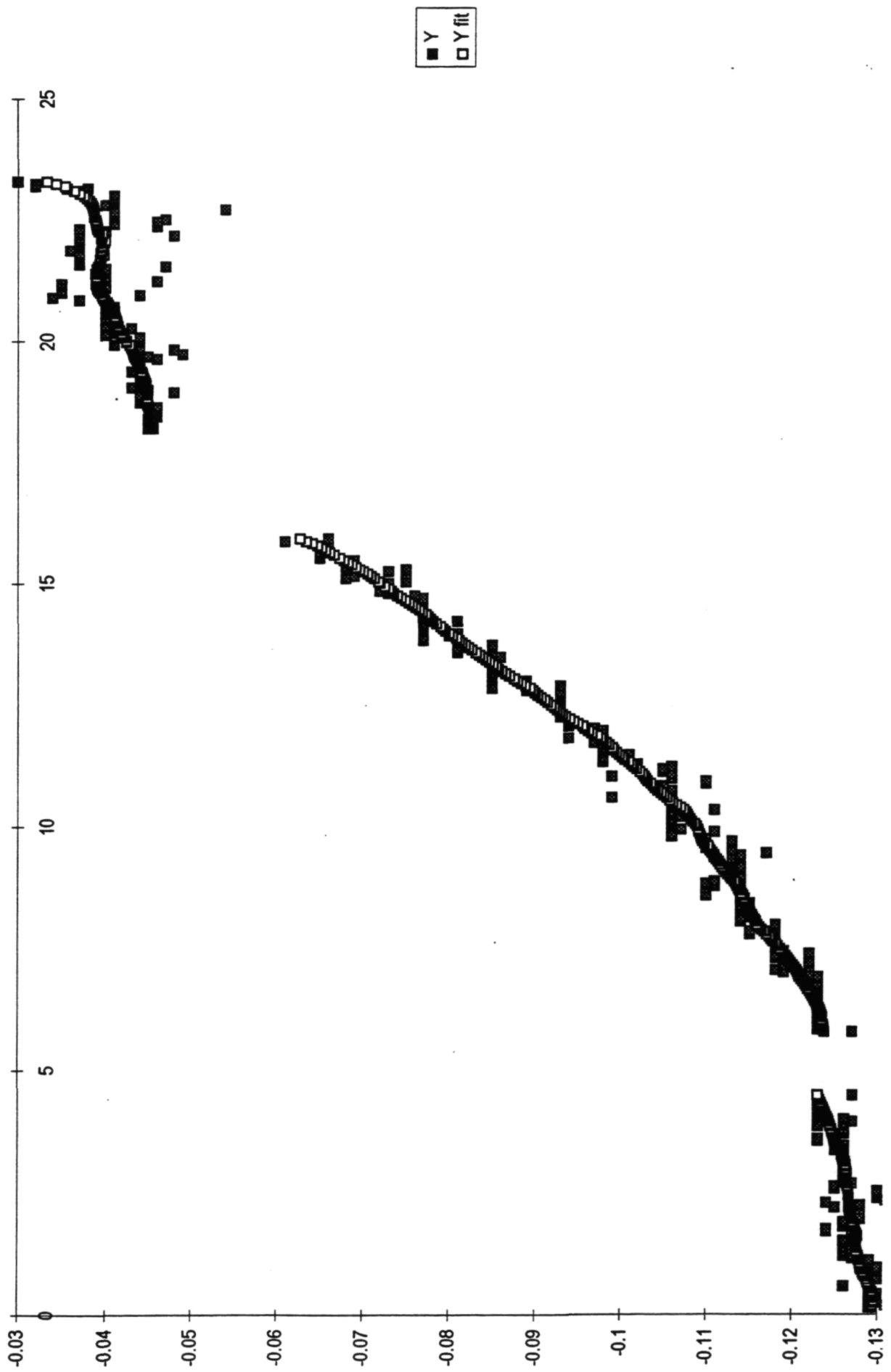


Figure 4-16. Plate 10 Y data vs. line fit

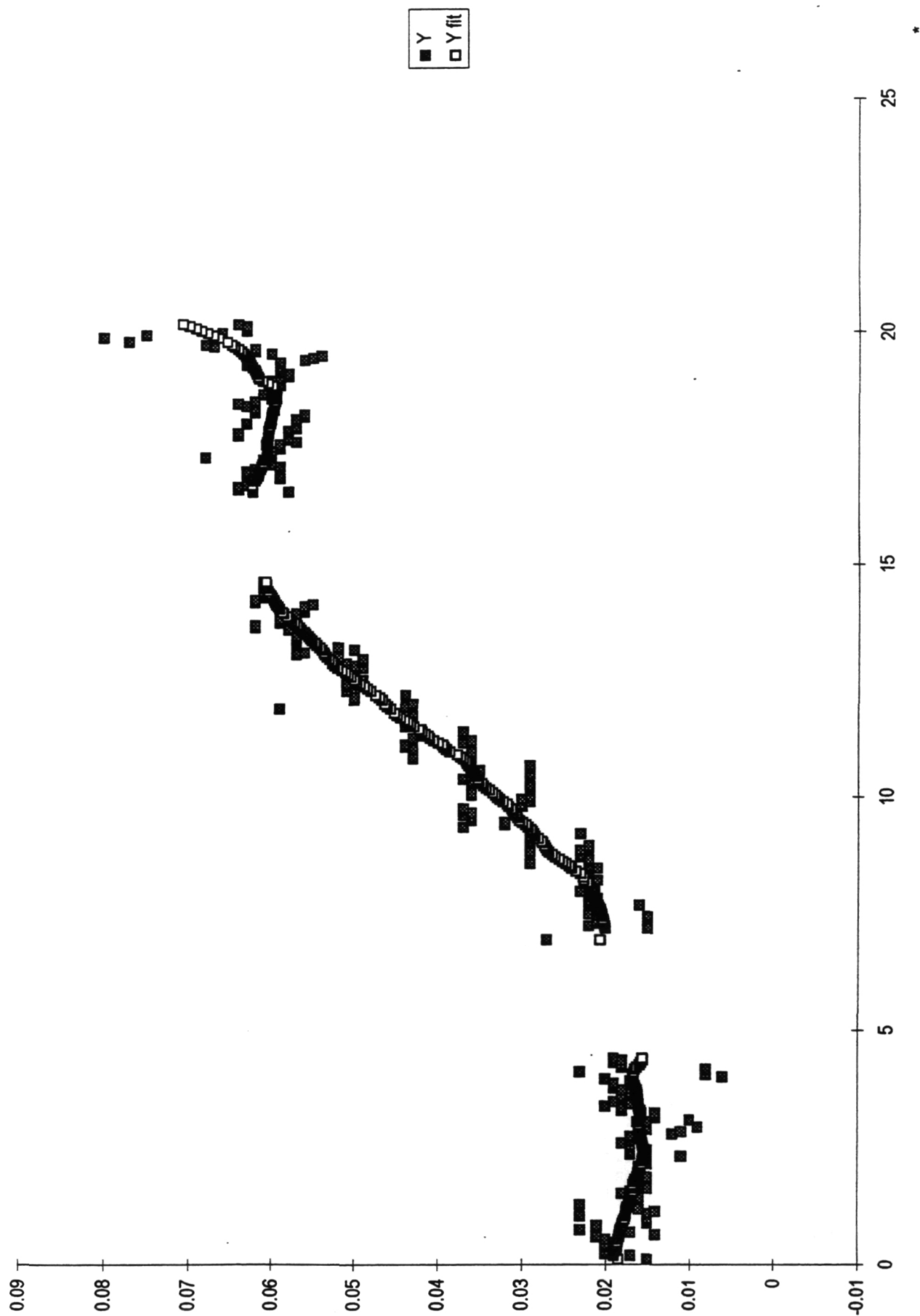


Figure 4-17. Plate 14 Y data vs. line fit

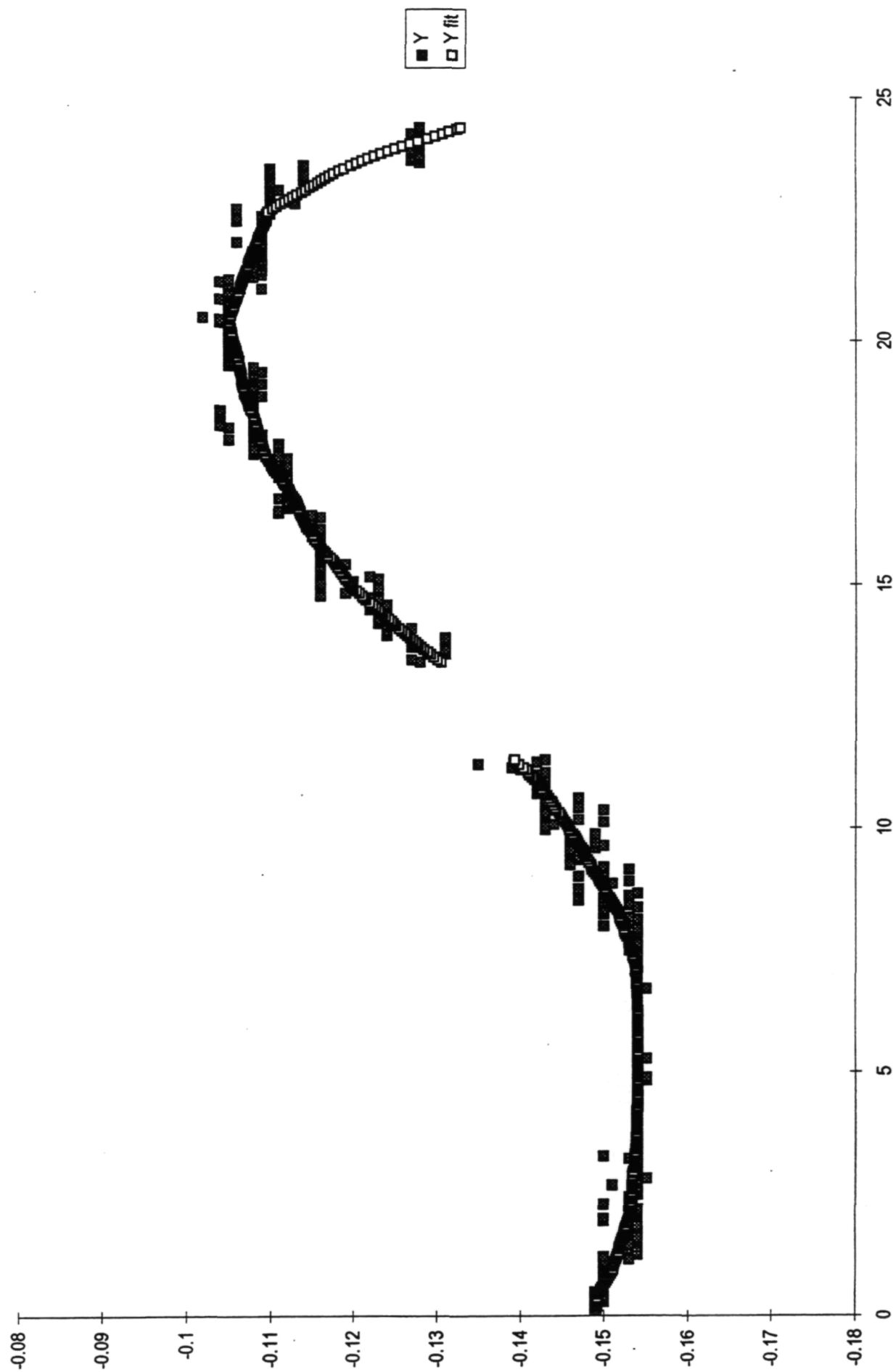
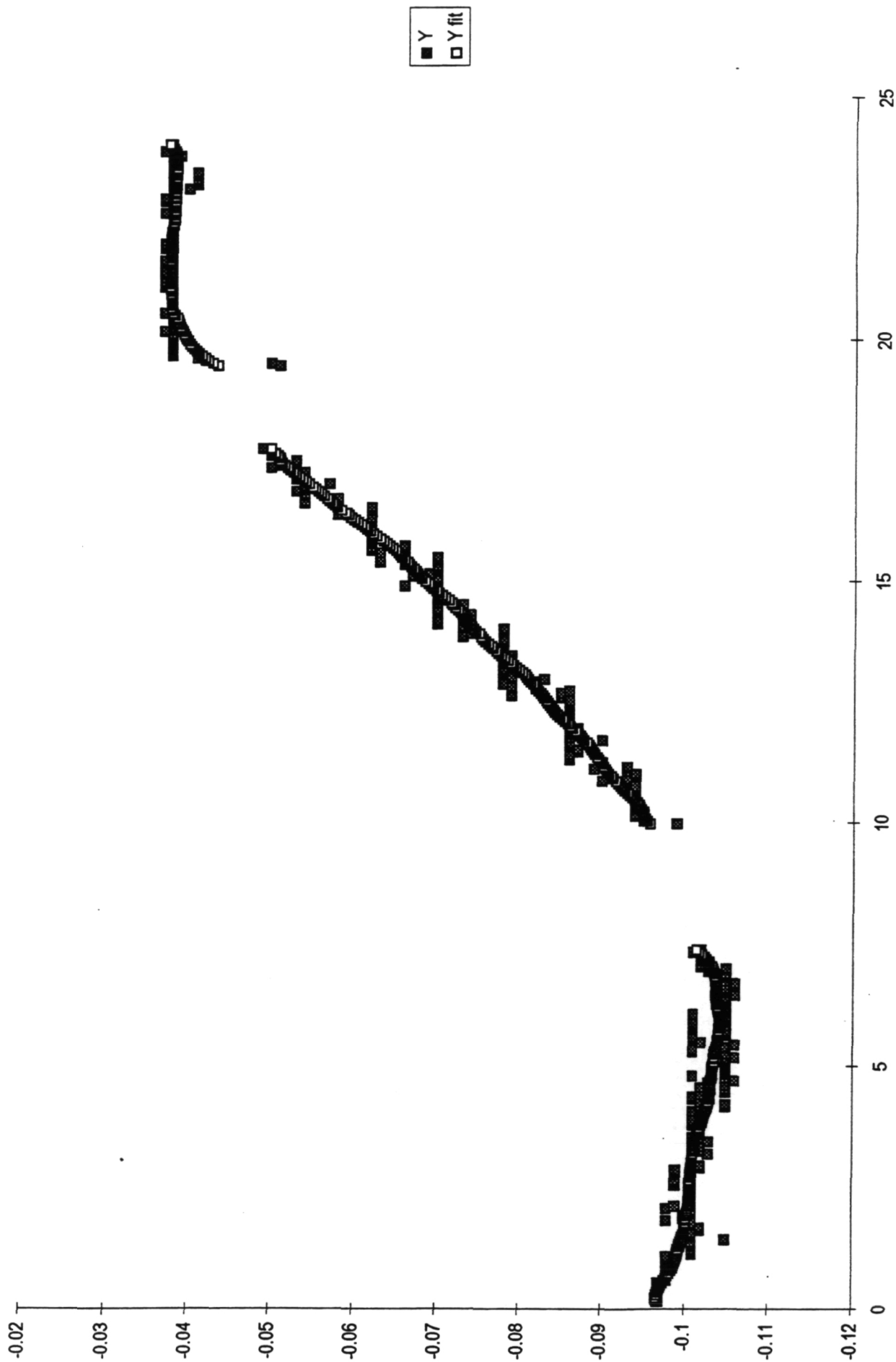


Figure 4-18. Plate 15 Y data vs. line fit



algorithm, the tool motion causes the track path to look curved or stepped and responds by rejection of the points which do not pass the acceptance criteria.

The new tracking sensor reduces the effect of tool motion by moving the sensor closer to the torch. One effect of this is to reduce the amount of unmeasured travel the torch moves between the time a seam point is taken to the time the torch must react to it. Figures 4-19 and 4-20 show a plot of the tracking error due to tool runout error for sensor to torch distances of 8 inches, 2 inches and 1 inch using a least squares approximation for 2" of data. Seam measurement error is not added into this tool runout error.

4.6 Stereo Seam Tracking Sensor Future Enhancements

Based upon the testing of the advanced seam tracking sensor, two improvements have been identified as limitations to the new design:

- standoff measurement not always reliable
- viewing angle of keyhole view not sufficient for all setups.

Since the sensor utilized laser illumination for standoff measurements, ability to measure standoff was dependent upon the surface finish of the plates being welded. Both the highly reflective machined plates and the rough surface of stock aluminum plates would yield a high amount of scatter, making the measurements unusable for track point verification or seam location identification. An independent method for measuring standoff should be devised and implemented which is independent on surface finish.

Also increasing the angle of the keyhole view is necessary to give more flexibility for the positioning of the tracking sensor. The current viewing angle does not always allow imaging of the leading edge of the keyhole.

Figure 4-19
Simulated Error

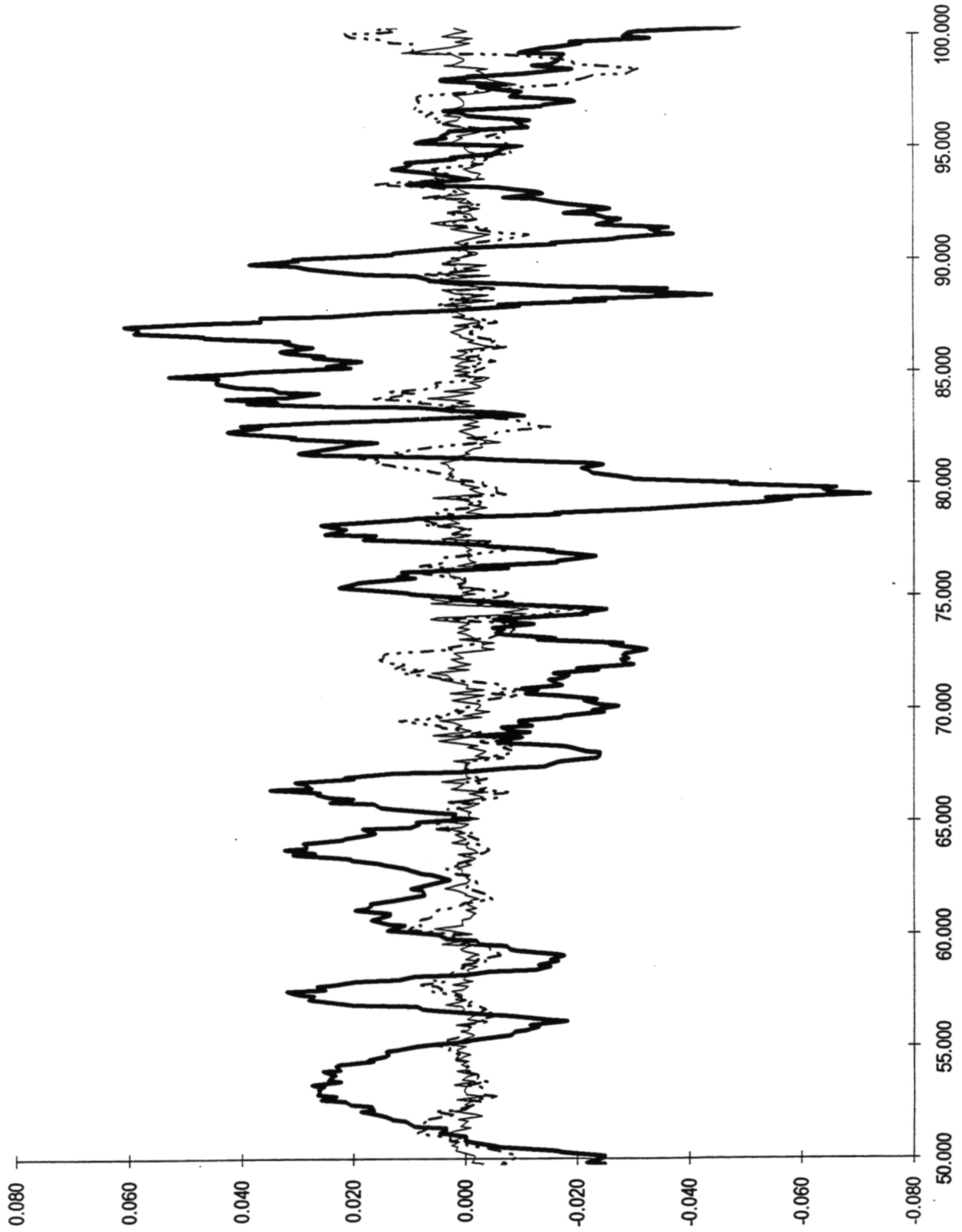
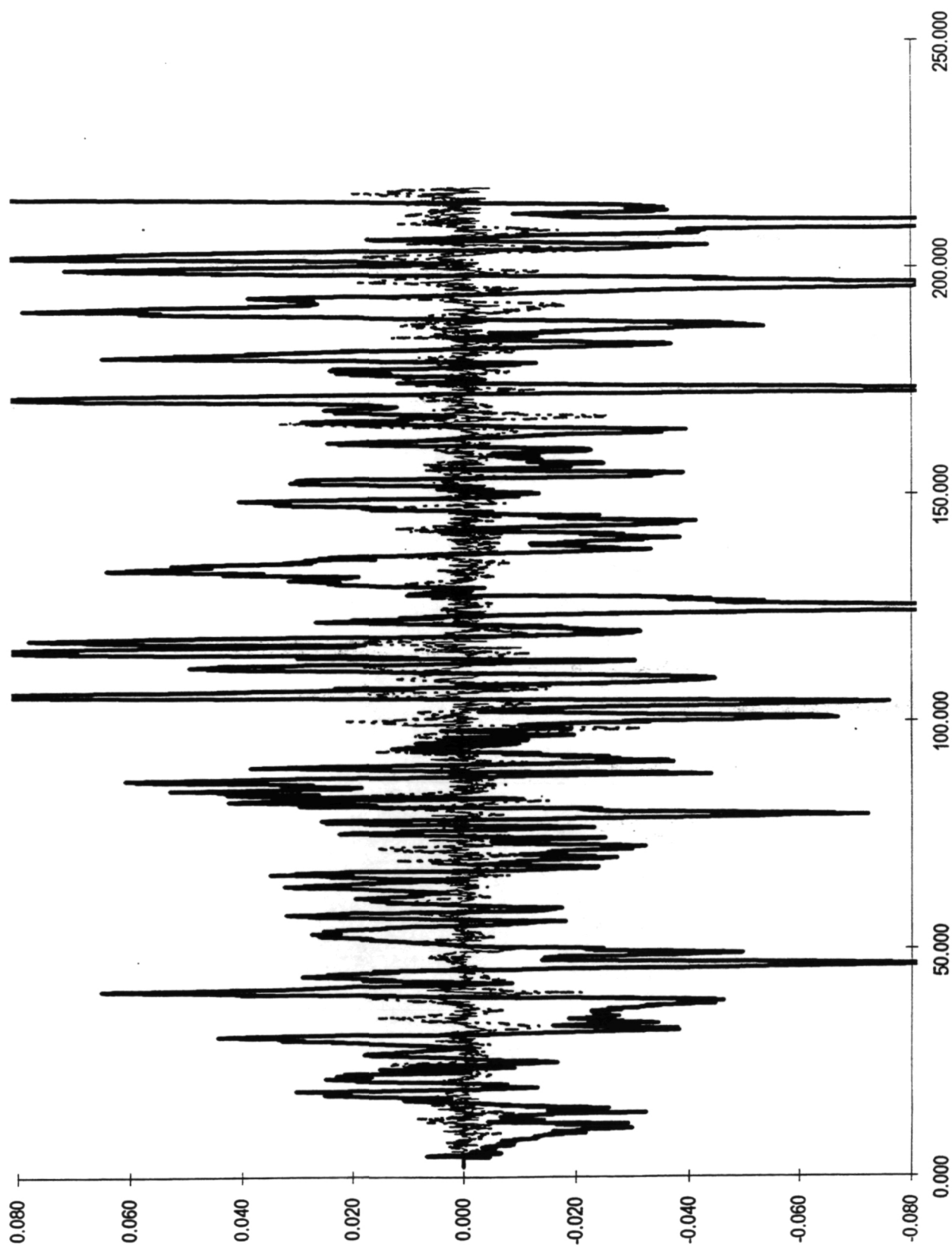
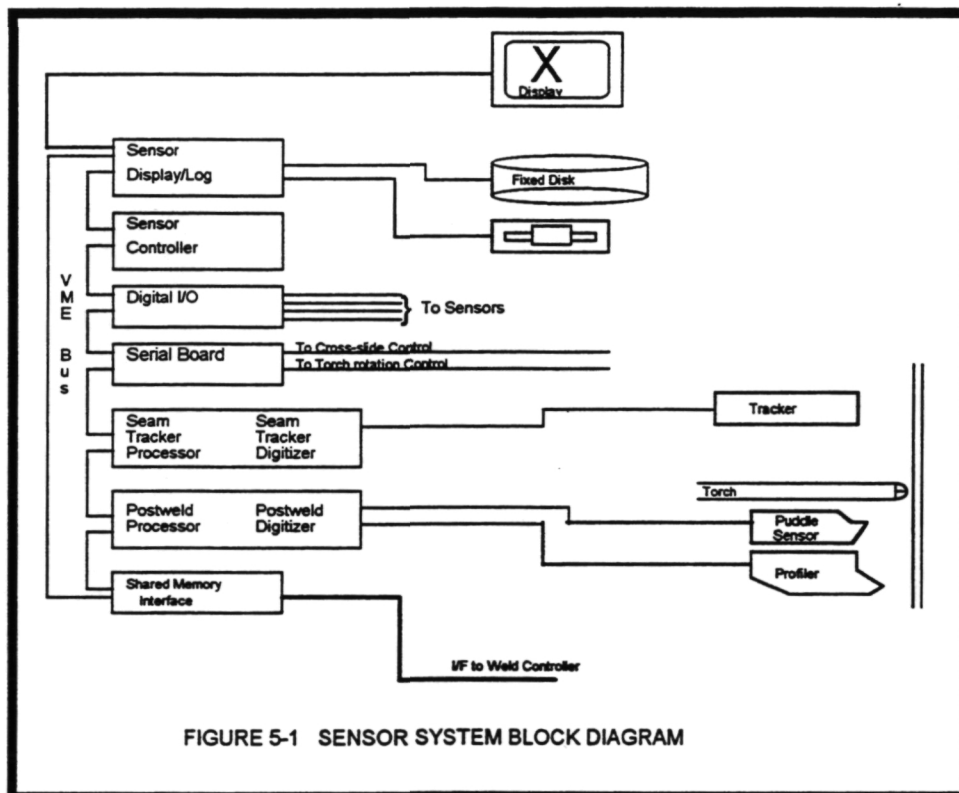


Figure 4-20
Simulated Error



5.0 Sensor System Software/Hardware Design

The sensor system is a real time, multi-processor, multi-tasking VME bus based platform which is interfaced to the individual weld sensors. Though not implemented on this particular system torch rotation and cross slide motion control can be added easily. Figure 5-1 shows a block diagram of the designed sensor system. The system computer uses the Microware OS9 real time operating system and all software is written in the C programming language.



The use of multiple processors allows sensor processing functions to be distributed thus introducing a high degree of parallelism with subsequent processing speed enhancement. Real time multi-tasking improves software design, functionality and maintainability by keeping the system and sensor supervision, data logging and motion control functions as separate tasks, thereby avoiding the problems associated with a large amorphous piece of code that does everything. Since the operating system is real time an individual task will perform its functions at known time intervals which is critical for

accurate data logging and motion control. Also this design allows easy addition of sensors by simply adding another processor.

5.1 Overall Design

The system processing functions are divided between a host processor and slave processor. The host processor runs the tasks which supervise the system, log data, execute weld schedules and control cross slide and torch rotation. This processor is a Force CPU-30ZBE board with a 30MHz Motorola 68030 CPU with four megabytes of memory. Sensor outputs are processed on a slave processor and video frame grabber pair in the form of an Ironics Incorporated IV-PCPU30 pipeline CPU and IV-VFGD Video Frame Grabber and Display. The design allows for, and the software supports, all sensors to be processed by one board pair, or individually on PCPU/VFGD pairs dedicated to each sensor or any combination of two sensors on one pair and the other on a separate pair. This design differs from that proposed which was to use a ARI Hawkeye video acquisition board modified to interface to an Intel 80960 processor board as a pair to provide high speed dedicated processing of sensor video. The decision to change the proposed design was based on the fact that the Ironics video processing board pair satisfies the system design requirements of dedicated high speed sensor processing using off the shelf hardware thereby avoiding the cost and risk associated with a redesign of the ARI video acquisition board. Details of the Ironics board pair are discussed in a later section.

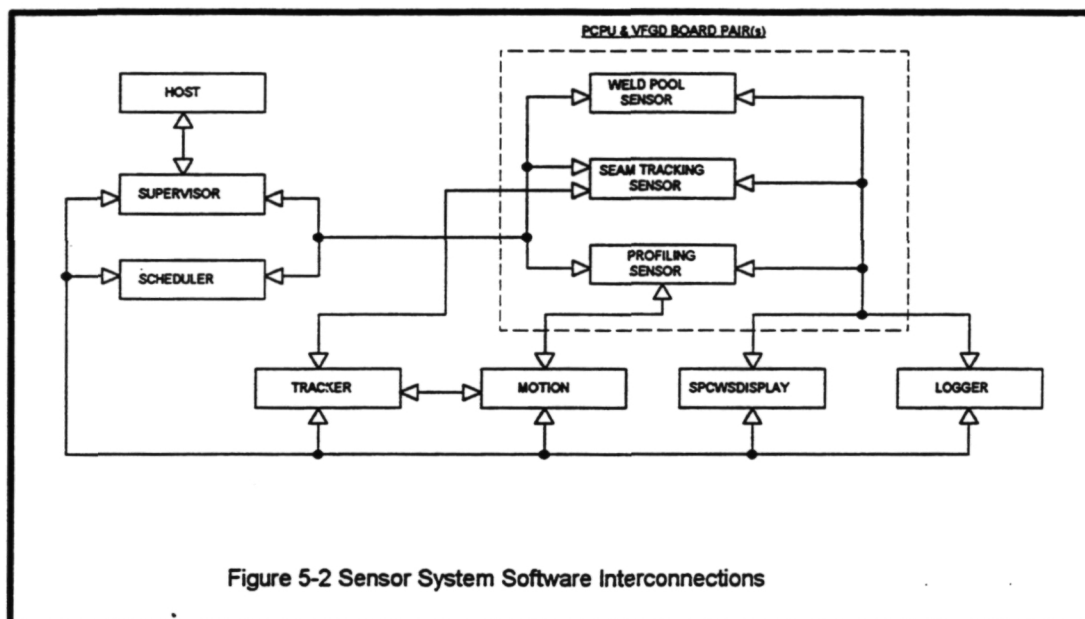
Software drivers are in place for the VMIC 64 bit digital input board VMIVME-1150 and for the VMIC 32 bit digital output board VMIVME-2170A. Addition of these boards for sensor control is a simple task. Sensor control is provided by the digital output board while sensor status is read by the digital input board. All sensor control and status lines are optically isolated from the system computer which offers high voltage protection and since the isolation essentially forms a current loop a large degree of noise immunity is also gained. The system delivered for this contract does not contain either of the digital I/O boards as they were not called for in the contract.

All the necessary software to control motion for the cross slide and torch rotation has been installed. The translation stages for cross slide, the rotation fixturing and motor specifications required for motion have been previously designed. Motion control hardware, based on these designs, has been implemented on other programs so that, although it was not called for in this contract, it would be straight forward to add motion control to this system at a later date.

Also installed on the sensor system is the software for communication to the Hobart HAWCS II Weld Controller via a Bit3 Computer Corporation Model 411 Memory-Mapped Bus-to-Bus VME bus adaptor which appears as local memory to each system. Commands, status, Parameter set points and data are exchanged through a "mail box" data structure mapped into this shared memory.

5.2 Sensor Processor and System Software Design

The sensor system software has been designed to be as modular as possible with a view toward maintainability and ease of adding additional sensors or future enhancements. System functions have been divided into several tasks which run as individual programs that communicate with each other through a "mailbox" communications arrangement. The system tasks for this system all run on the host processor in the multitasking environment created by the Microware Systems Corporation OS9 real-time operating system. The tasks could also be split between two or more slave processors, still maintaining multitasking on each processor. Figure 5-2 shows a diagram of the sensor system software interconnections.



A synopsis of the specific duties of the individual tasks is given below:

- The Host task is responsible for bringing up the sensor system software. It down loads the sensor processor software to the PCPU(s), creates all the "mailbox" communication structures, initializes sensor processor and system parameters, starts all the individual tasks, and serves as a text oriented terminal user interface. Host also gracefully terminates the sensor system software.
- The Supervisor task coordinates the sensor system to insure proper execution of commands from the user or from external sources such as the weld controller. Supervisor starts the scheduler task if a weld schedule is to be executed or sends commands to the sensors if the system is operating in a stand alone mode. Supervisor is responsible for sending weld sequence commands as required to the other tasks. Also it keeps system time for all tasks and sensors so that data logging and error reporting can be time stamped. Supervisor verifies the integrity of the shared mailbox data structures at all times . Also it performs an operations check on all tasks periodically to verify that each is still running by setting a flag in each tasks and sensors mail box that is reset by the task or sensor.
- The Scheduler task executes predefined sensor weld schedules which send sequencing commands to the sensors. Scheduler also converts schedules stored on disk as ASCII text files to schedule steps to be executed during a weld and stores this into memory prior to the weld. Scheduler has the ability to trigger external events and to wait on external events before continuing with the schedule.
- The Logger task saves data in the log buffers to the fixed disk during a weld. Data is placed in the log buffers by the various tasks and the sensor processors.
- Torch cross slide and rotation is driven by the Motion task which interfaces the system with motors used for motion. Position commands are sent to Motion by the other tasks and Motion in turn sends the actual current position to the other tasks.
- The Tracker task verifies the Seam Tracker output of seam points by comparing the latest seam point to a running history of the track path. Tracker also generates cross slide velocity from the torch position and track path.
- The task SPCWS display provides all tasks and sensor processors a means to display information on the overlay plane of any of the VFGDs output video. This

information can be alpha numeric text, data plots or feature highlight marks (vertical or horizontal marks, or cross hairs) of different sizes and intensity. This is useful for marking features such as track points, bead edges from the Profiler, torch center from the weld pool imager or plotting bead profile from the Profiler to name just a few.

The software containing the sensor processing algorithms is down loaded from the host processor into program memory on the PCPU. Since video data and processing code are both present on the PCPU board, sensor processing is performed local to the CPU. This increases sensor video processing speed because this local PCPU bus is faster than the VME bus. Also the added benefit of keeping the sensor processing entirely off of the VME bus, except for a small amount of communications and reporting of process results, is realized thereby reducing the traffic on the VME bus with resulting improvement in overall system performance. Communications between the host processor and the PCPU are accomplished through a "mailbox" communications data module mapped onto the PCPU local memory. The software for the individual sensor processors will be discussed in more detail in their respective following sections.

5.3 Sensor Processor Hardware

Sensor video is processed using the Ironics Incorporated IV-PCPU30 pipeline CPU and IV-VFGD Video Frame Grabber and Display which form a dedicated slave processor and video frame grabber pair. Video from sensors is digitized by the VFGD and sent via a private data bus directly to frame storage memory on the PCPU where it can be processed locally with no impact on the main VME bus.

5.3.1 CPU

The IV-PCPU-30 VME bus Pipeline CPU board is an extremely powerful and versatile slave processor designed for applications in computer graphics, image processing, and data acquisition. The wide range of possible CPU clock frequencies makes the IV-PCPU-30 ideal for applications which require very high computational power as well as a general-purpose "number cruncher".

The IV-PCPU-30 is based on a 68030 processor running at 25 MHz as standard, with 33 and 50 MHz clock frequencies available as options. The processors in the sensor

system run at 25 MHz. The 68030 processor has a very powerful instruction set which is upward compatible with 680x0 processors. The 32-bit-wide data and address paths allow large arrays of data images to be accessed randomly, quickly, and efficiently. The built-in caches on the 68030 CPU provide very high throughput, and a 68882 Floating Point Coprocessor is particularly useful for video image processing applications.

The IV-PCPU-30 provides 4 Mbytes of dual-ported video RAMS (VRAMs), capable of storing four complete video images, any of which can be accessed by the processor while data acquisition is in progress. The video RAM may be used as either program/data memory and/or frame buffers for storing acquired image data.

Onboard static RAM (up to 512 kbyte) provides 32-bit-wide, high-speed accesses. Up to 1 Mbyte of EPROM for resident software can be installed in place of the SRAM in cases where a turn key system is desired. A 2 kbyte non-volatile RAM (NVRAM) can be installed for calibration data in self-contained systems. The NVRAM also contains a buffered real-time clock to provide system time. Figure 5-3 shows a block diagram of the PCPU-30.

Features of the IV-PCPU-30 include

- Onboard MC68030 CPU running at 29, 33 or 50 MHz
- Optional 68882 Floating Point Processor
- Bi-directional Video Interface Bus (VIB) supporting interlaced, non-interlaced, process-mode, and non-raster data formats
- VI Bus data width of 8 or 16 bits-per-pixel with contiguous storage
- 4Mbyte video RAM for image and data/program storage
- Four 32-pin JEDEC sockets for 512 kbyte SRAM or up to 1 Mbyte EPROM
- 2 kbyte NVRAM with real-time clock
- DUART chip providing two serial channels, local interrupts, and parallel I/O
- VME bus interface with 32-bit capability and interrupt generator
- VSB master interface
- Intelligent Graphics Interface (IGI) connector

5.3.2 Frame Grabber

The Ironics IV-VFGD VME bus Video Frame Grabber and Display is a general-purpose image processing board. It contains all of the functions necessary to digitize standard video camera signals and to display digital images on standard monitors. In its simplest application, the IV-VFGD is connected (via the VME bus) to a CPU board performing image processing.

In the sensor system the IV-VFGD is as a front-end for the PCPU forming a pipelined image processing system. Digital video data is transferred in real-time from the IV-VFGD to the PCPU processing board via the Video Interface Bus (VIB). In this configuration images can be processed by the PCPU without accessing the VME bus thus increasing overall system speed.

Video signals may be acquired in either 625-line CCIR or in 525-line EIA format. Up to four cameras may be connected to the IV-VFGD. One of these inputs is selected by an analog multiplexer contained on the IV-VFGD. The standard digitization rate of 14.3 Msample/s makes square pixels possible, even at higher television scan rates. This feature also makes it easier to measure diagonal distances directly from the picture, without additional scaling operations.

Four input look-up tables may be used to transform the gray-scale of the incoming digitized signal to different gray-scales, or binary, in real-time. This is particularly useful for linearizing the outputs of cameras with $\text{Gamma} < 1$. Programmable offset and gain settings for the A/D converter offer additional adjustment capabilities.

Pictures are acquired in interlaced or noninterlaced format to optimize for high resolution or for fast acquisition of moving objects. Acquired video data is placed sequentially in video memory in ascending byte addresses. Each starting pixel of a video line is assigned to an address that is determined by the address look-up table. In non-interlace mode, the video lines are put to sequential lines. In interlace mode, only the even blocks are filled in the even video field; and the odd blocks in the odd field. Thus, the proper geometric order is maintained for both cases.

Two, one-megapixel video frame buffers facilitate storage of two full-size pictures, or short sequences of smaller ones. A stored picture may be displayed from one frame buffer, while simultaneously acquiring and storing picture data in the second buffer.

Display capabilities include a color look-up table for display of either gray-scale or pseudo-color pictures. The analog video output has a resolution of 8 bits-per-channel. A separate, one-megapixel overlay frame buffer allows 15 simultaneous overlay colors, independent of the two video frame buffers.

A 32-bit VME bus interface allows the IV-VFGD be connected to any 16-bit or 32-bit VME bus system. Video memories (VRAMs) allow independent access from the bus, even if an acquisition is under way, without speed penalty. The wide access path is essential when large amounts of data must be moved quickly.

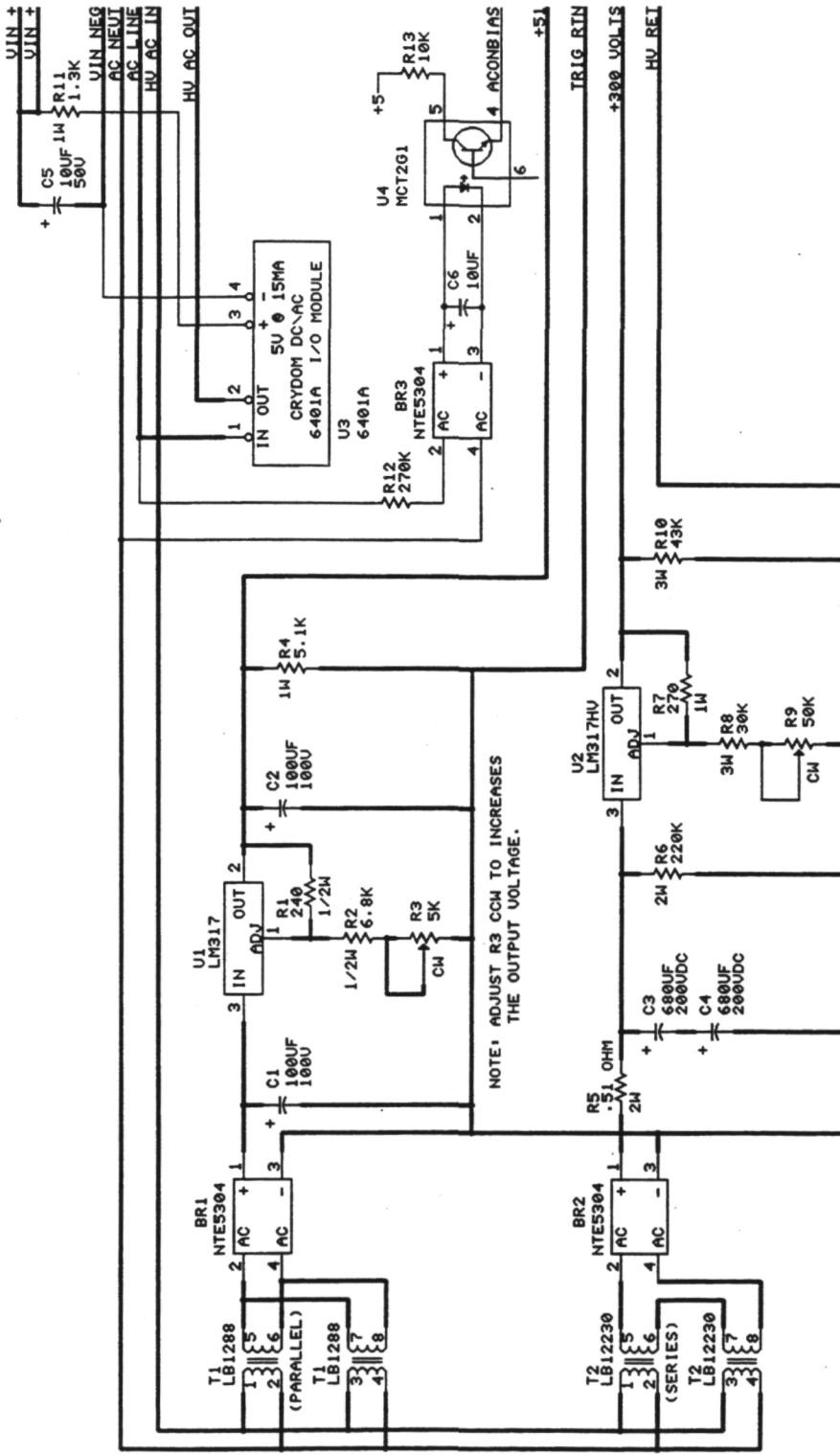
The VIB interface is a bidirectional, sequential port for real-time data transfer with a rate of up to 14.3 Mbytes per second. It can be used both for input into the IV-VFGD and for output to the next pipeline stages. Data is accessed from the A/D converter and subsequent input look-up table, or from one of the frame buffers. See figure 5-4 for a block diagram of the IV-VFGD.

Features of the IV-VFGD include:

- Two, 256-color, 1K x 1K video frame buffers
- Two independent windows for acquisition and display
- A 15-color, 1K x 1K overlay frame buffer
- Color look-up table for 256 simultaneous colors out of 16 million (8-bit DACs)
- Video input multiplexer for up to four video input signals
- Sampling rate up to 14.3 Msample/s with 8 bits-per-pixel
- Selectable CCIR or EIA video formats (625 or 525 lines)
- Square pixels obtainable with CCIR and EIA video formats
- Programmable offset and gain settings of A/D converter
- Four 256 x 8-bit input look-up tables
- External clock input
- Internal or external sync
- External trigger
- Interlaced or non-interlaced operation

- Video Interface Bus for real-time, bidirectional transfer of video data
- 32-bit VME bus interface
- Onboard vector interrupts

Appendix A Sensor Schematics



NOTE: ADJUST R3 CCM TO INCREASES THE OUTPUT VOLTAGE.

NOTE: ADJUST R9 CCM TO INCREASES THE OUTPUT VOLTAGE.

APPLIED RESEARCH INC. 6700 ODYSSEY DRIVE HUNTSVILLE AL 35806	
PROFILING IMAGER SYSTEM	
D INSM	HIGH VOLTAGE BOARD
ARCS MODEL 88P-100 DEVELOPMENT #4300-001	POWERBRD.P01 1 10/25/92

HIGH VOLTAGE BOARD

P1

E2M280REH



NOTE: JUMPER ACROSS R16

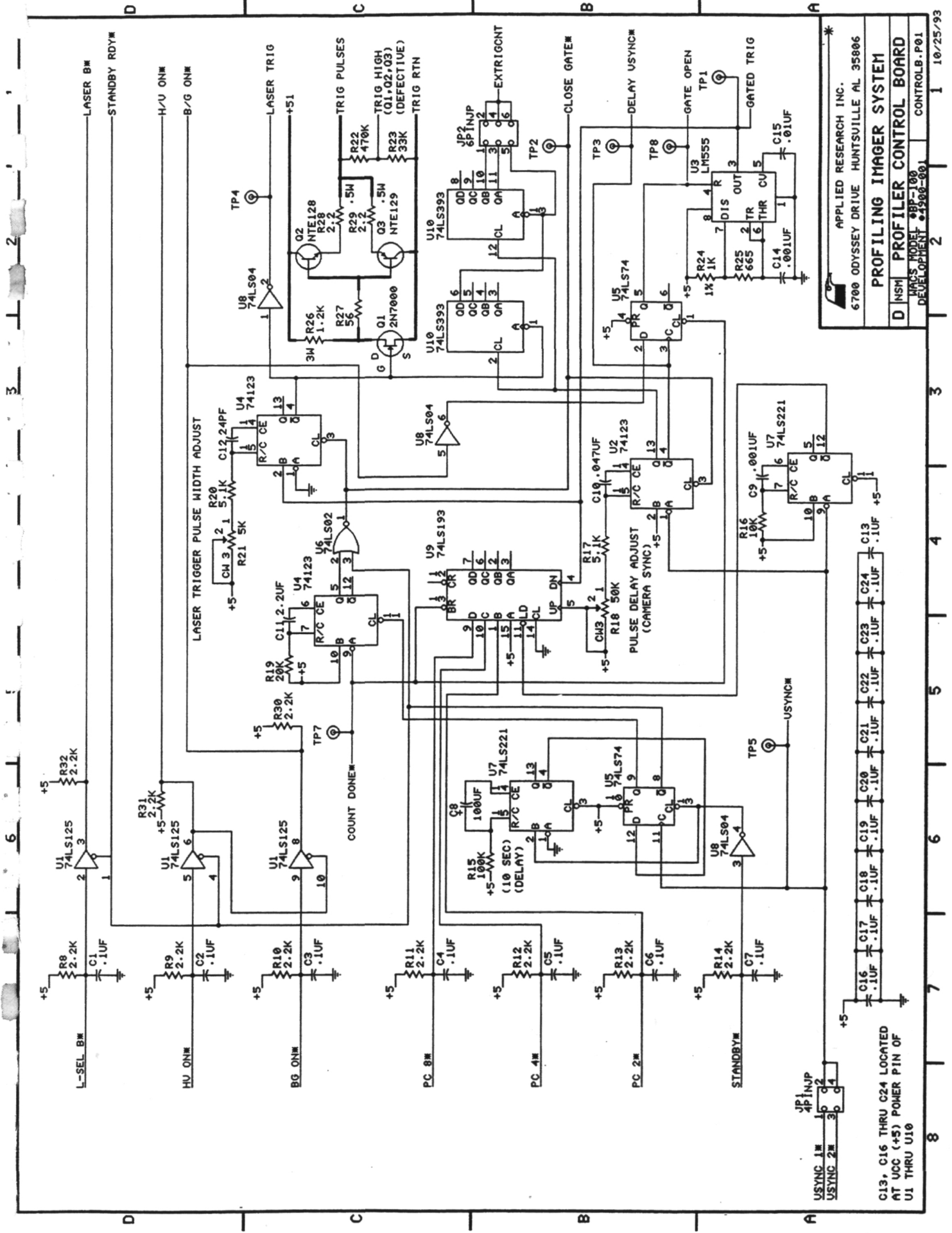
APPLIED RESEARCH INC.
6700 ODYSSEY DRIVE HUNTSVILLE AL 35806

PROFILING IMAGER SYSTEM

HIGH VOLTAGE BOARD

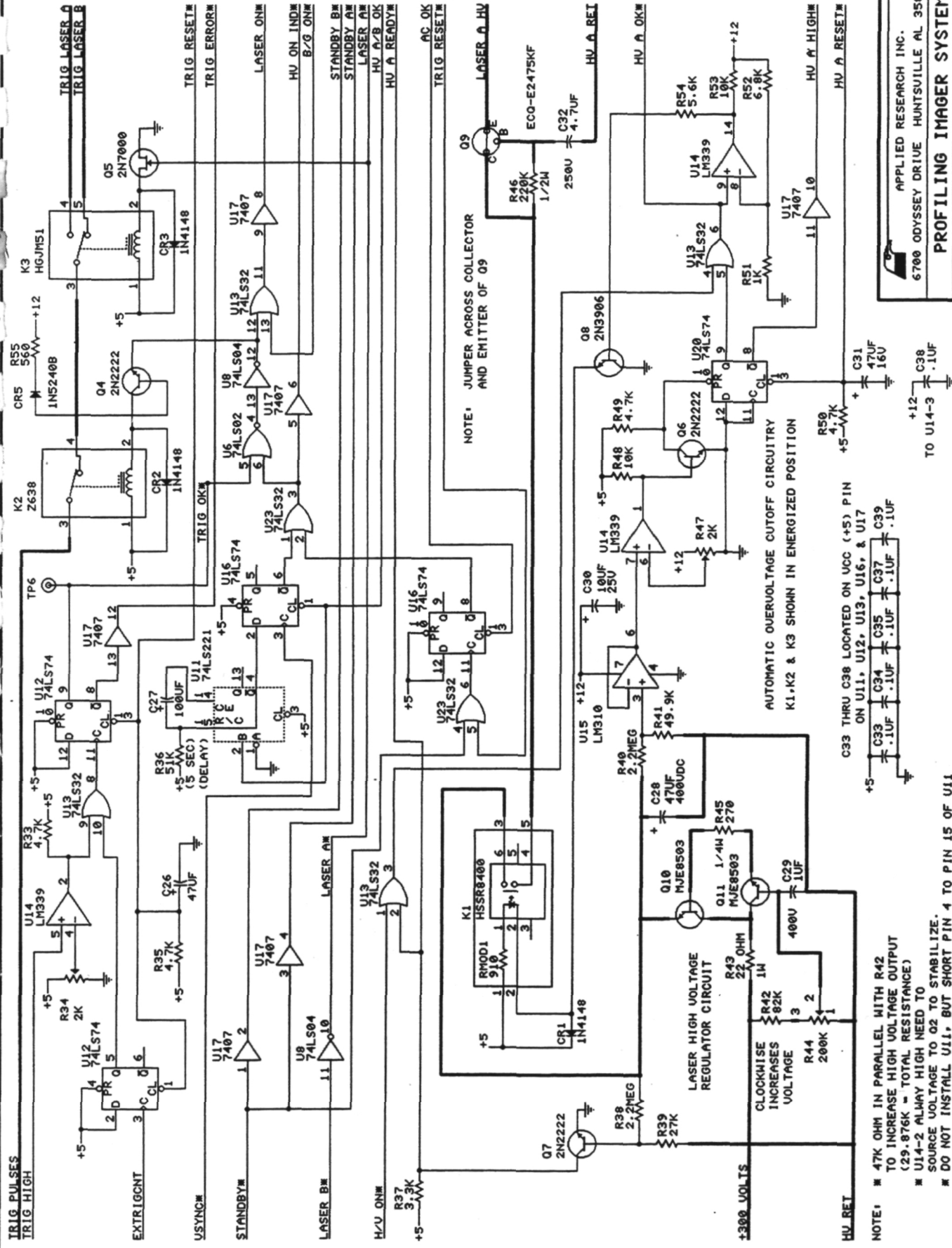
INSM MODEL 88P-100
DEVELOPMENT #4300-001 P0MERBRD.P02

10/25/93



APPLIED RESEARCH INC. 6700 ODYSSEY DRIVE HUNTSVILLE AL 35806	
PROFILER IMAGER SYSTEM	
D NSM	MACS MODEL 88P-100 DEVELOPMENT 4500-001
CONTROL B. P01	

C13, C16 THRU C24 LOCATED
 AT UCC (+5) POWER PIN OF
 U1 THRU U10



NOTE: * 47K OHM IN PARALLEL WITH R42 TO INCREASE HIGH VOLTAGE OUTPUT (29.876K = TOTAL RESISTANCE)
 * U14-2 ALWAYS HIGH NEED TO SOURCE VOLTAGE TO Q2 TO STABILIZE.
 * DO NOT INSTALL U11, BUT SHORT PIN 4 TO PIN 15 OF U11

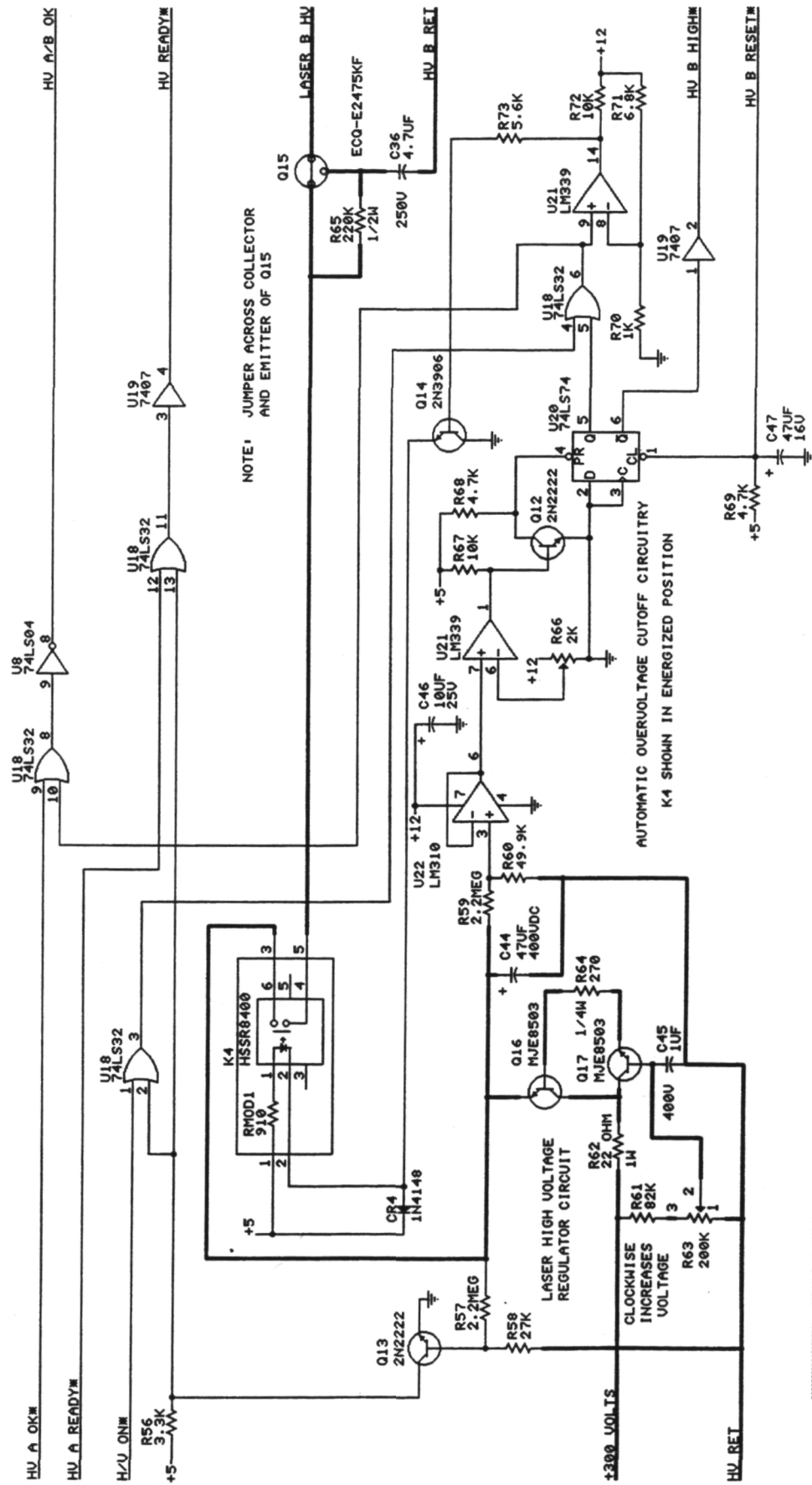
C33 THRU C38 LOCATED ON UCC (+5) PIN
 ON U11, U12, U13, U16, & U17
 C33 .1UF C34 .1UF C35 .1UF C37 .1UF C39 .1UF
 TO U14-3 .1UF

AUTOMATIC OVERVOLTAGE CUTOFF CIRCUITRY
 K1, K2 & K3 SHOWN IN ENERGIZED POSITION

NOTE: JUMPER ACROSS COLLECTOR AND EMITTER OF Q9

APPLIED RESEARCH INC.	
6700 ODYSSEY DRIVE HUNTSVILLE AL 35806	
PROFILING IMAGER SYSTEM	
D NSM	PROFILER CONTROL BOARD
MSX MODEL 88P-100	CONTROL B-P02
DEVELOPMENT #4906-001	

* DANGER ! THIS UNIT SUPPLIES EXTREMELY HIGH VOLTAGE TO THE REAR OUTPUT PANEL CONNECTOR



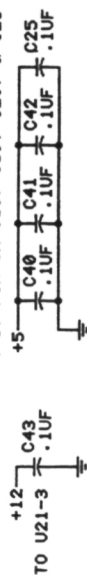
	OHM	VOLTS
①	3.38M	675 HV
②	4.1M	663HV

TIP50

ALL OTHER WAYS OF PROBING PART IS OPEN
(THIS IS WITH PART OUT OF CKT.)

(+ LEAD) (- LEAD)

C25, C40, C41, & C42 LOCATED ON UCC
(+5) PIN ON U18, U19, U20, & U23



APPLIED RESEARCH INC.
6700 ODYSSEY DRIVE HUNTSVILLE AL 35896

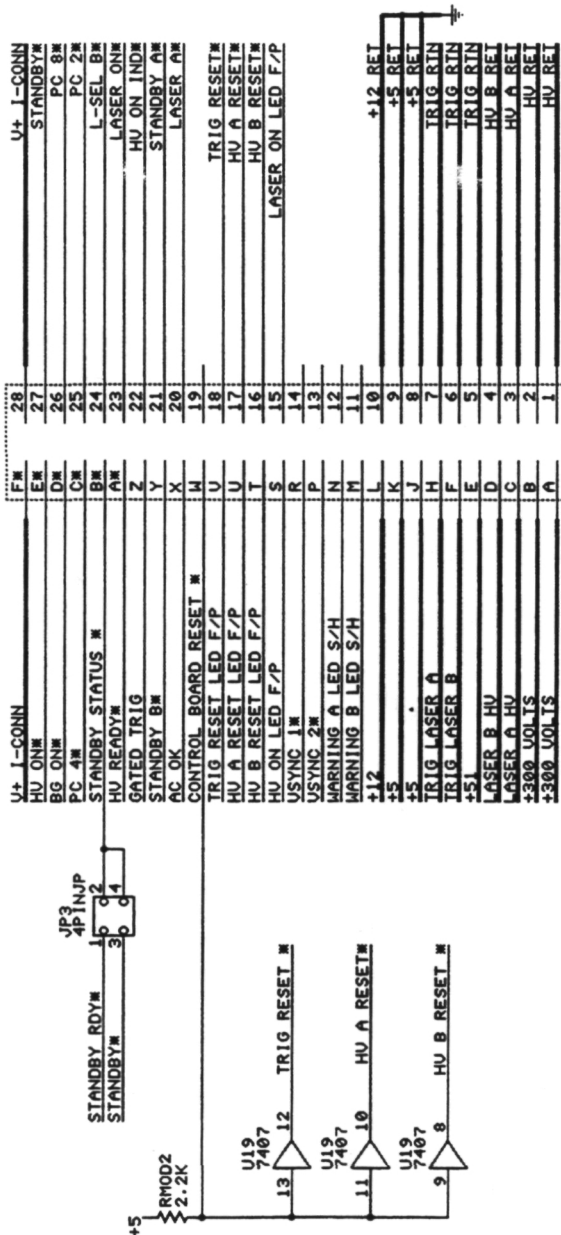
PROFILING IMAGER SYSTEM

D NSM PROFILER CONTROL BOARD
HCS MODEL 98P-100
DEVELOPMENT 4986-001 CONTROLB.P03

DANGER !
THIS UNIT SUPPLIES EXTREMELY HIGH VOLTAGE TO THE REAR OUTPUT PANEL CONNECTOR

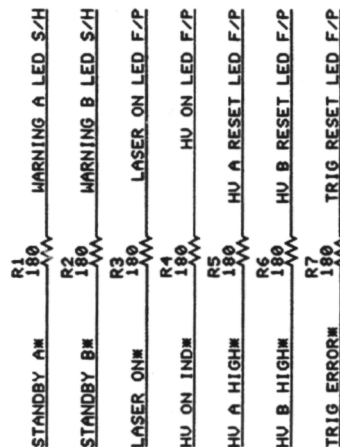
CONTROL BOARD

P1
EZM28DEH



NOTE: * MOD TO MAKE LASER WARNING LAMP
COME ON AS SOON AS STANDBY
INITIATED BY THE COMPUTER

- CUT TRACE FROM U17-9 TO U13-11
ON THE CIRCUIT SIDE OF THE BOARD
- CONNECT WIRE FROM U17-9 TO JP3-1
- CONNECT WIRE FROM U11-3 TO U11-15
- RM022 ATTACH ON U19-9 AND U19-14



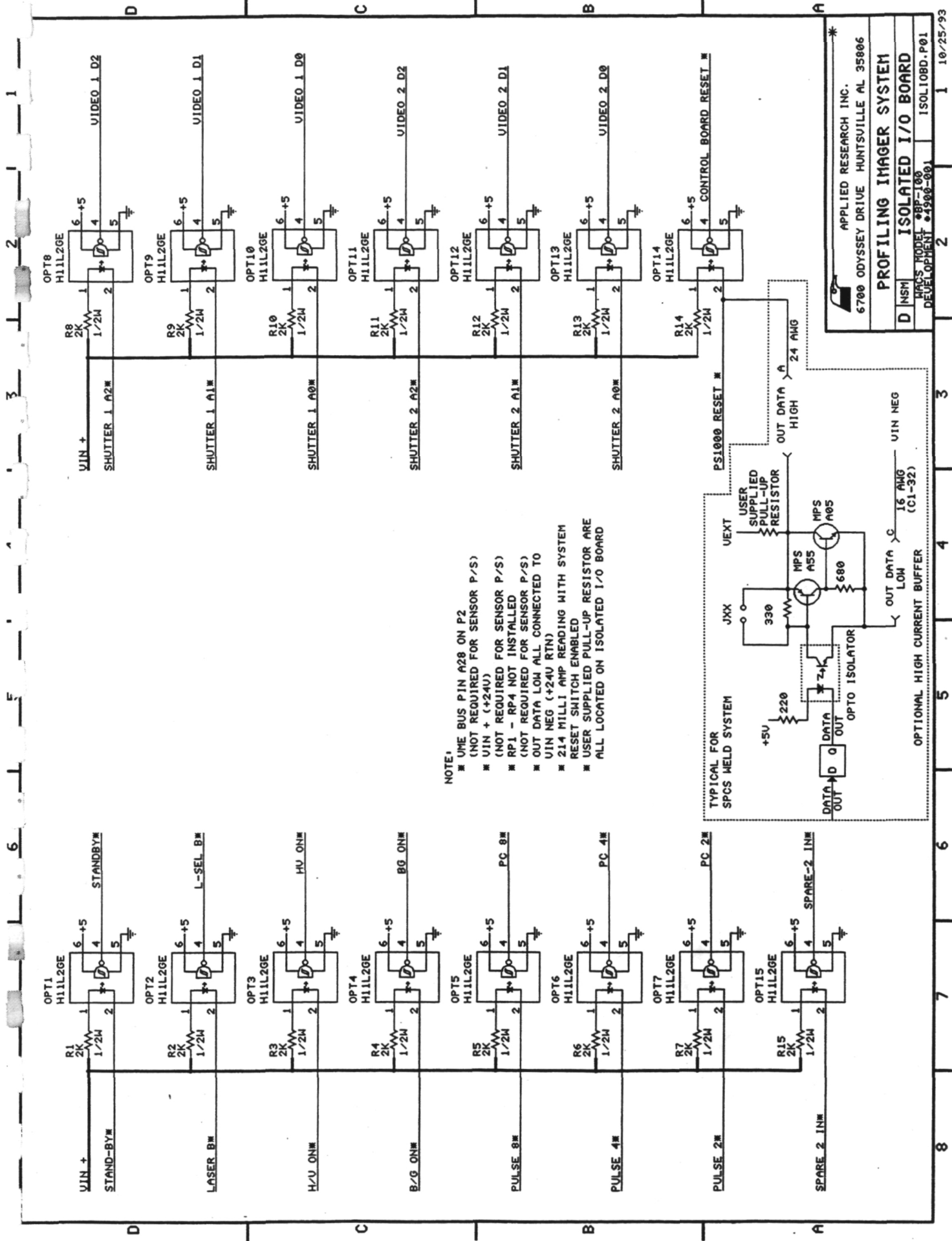
APPLIED RESEARCH INC.
6700 ODYSSEY DRIVE HUNTSVILLE AL 35806

PROFILER IMAGER SYSTEM

D INSM PROFILER CONTROL BOARD

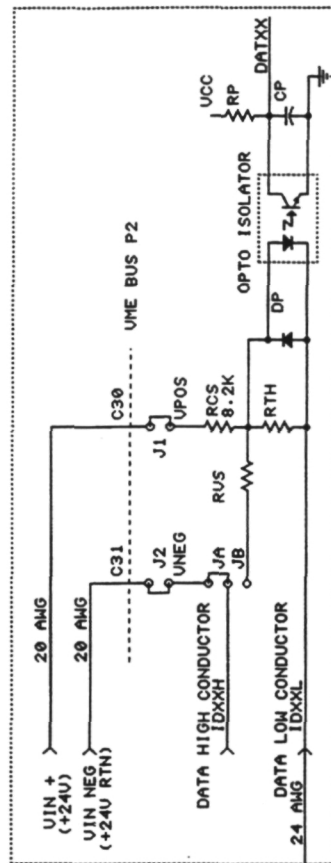
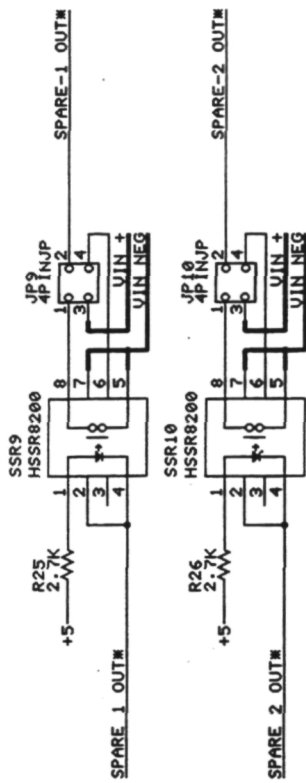
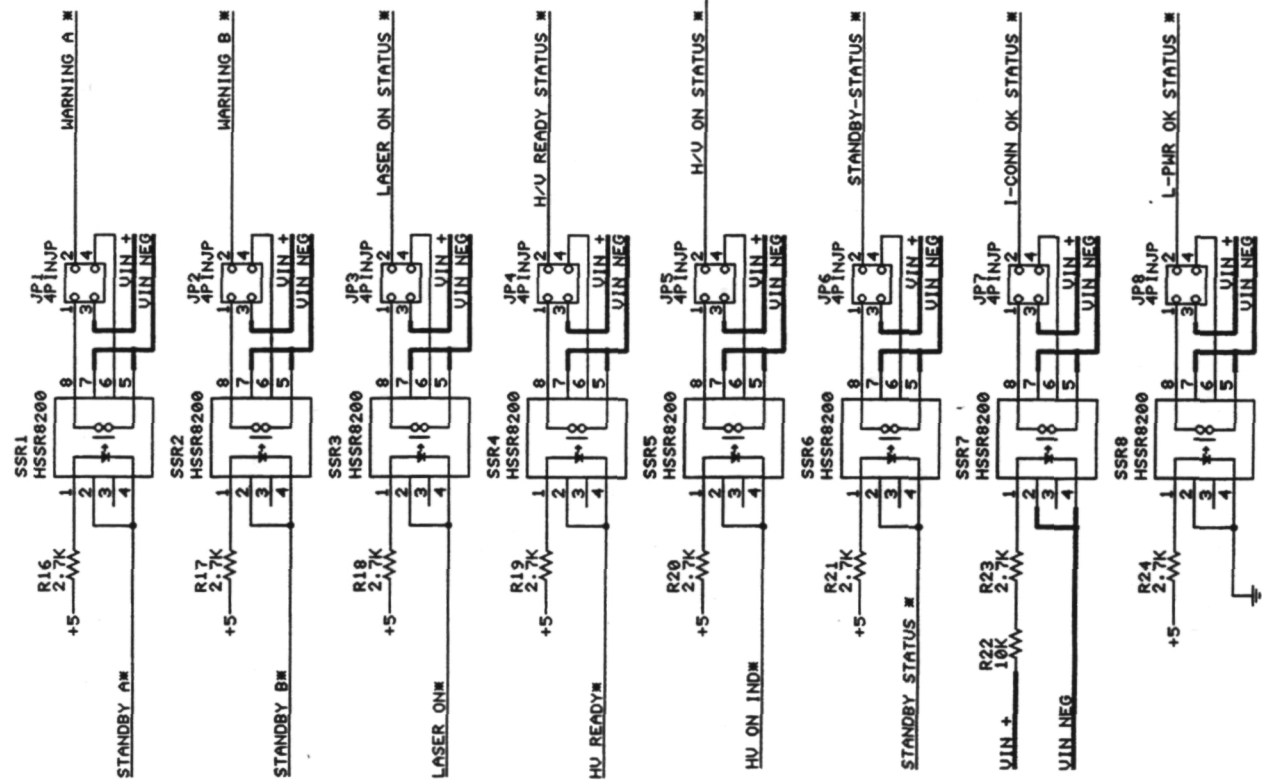
HACS MODEL 48P-100
DEVELOPMENT 4900-001 CONTROL B. P04

1 10/25/93



NOTE:
 * UNE BUS PIN A28 ON P2
 (NOT REQUIRED FOR SENSOR P/S)
 * VIN + (+24V)
 (NOT REQUIRED FOR SENSOR P/S)
 * RP1 - RP4 NOT INSTALLED
 (NOT REQUIRED FOR SENSOR P/S)
 * OUT DATA LOW ALL CONNECTED TO
 VIN NEG (+24V RTN)
 * 214 MILLI AMP READING WITH SYSTEM
 RESET SWITCH ENABLED
 * USER SUPPLIED PULL-UP RESISTOR ARE
 ALL LOCATED ON ISOLATED I/O BOARD

APPLIED RESEARCH INC. 6700 ODYSSEY DRIVE HUNTSVILLE AL 35806	
PROFILING IMAGER SYSTEM	
D NSM	ISOLATED I/O BOARD
MCS MODEL 288-100	
DEVELOPMENT 4986-001	
1	10/25/93



NOTE:

- JA WOULD BE J4 (IN)
- JB WOULD BE J37 (OUT)
- RCS IS ALREADY INSTALLED AND WOULD BE R18
- RP IS ALREADY INSTALLED AND WOULD BE 18K
- UMI/UME-1150 BOARD (SPC WELD SYSTEM)
- UNEG & UPOS JUMPERS (J1 & J2) MUST BE INSTALLED ONTO BOARD AND +24V RTN CONNECTED TO UME BUS PIN C31 AND +24V CONNECTED TO UME BUS PIN C30 ON P2
- TYPICAL CURRENT OUTPUT IF ALL OUTPUT LOW = (30MA @ 24V MAX)
- HSSR8400 IS 6 PIN DEVICE RATHER THAN 8 PIN DEVICE LIKE HSSR8200
- 5 MILLI AMP MINIMUM TURN ON CURRENT FOR HSSR8400 DEVICE
- SHORT OUT R22 AND KEEP R23 WITH 910 OHM FOR HSSR8400
- R16-R21 & R23-R26 = 910 OHM FOR HSSR8400
- MOD. FOR HSSR8400
- SHORT PIN 7 TO PIN 6
- INSTALL JUMPER PINS 1 & 2

APPLIED RESEARCH INC.	
6700 ODYSSEY DRIVE HUNTSVILLE AL 35806	
PROFILING IMAGER SYSTEM	
D NSM	ISOLATED I/O BOARD
HACS MODEL 88P-100	ISOL108D.P02
DEVELOPMENT 4500-001	1 10/25/93

ISOLATED I/O BOARD

P1
EZM280REH

VIN + INCON		VIN + INCON	
CR1 1N5394	+	28	28
+	5 RET	27	27
LOCAL PHR		26	26
HU ONM		25	25
BG ONM		24	24
PC 4M		23	23
VIDEO 2 D0		22	22
VIDEO 2 D1		21	21
VIDEO 2 D2		20	20
SPARE-2 INM		19	19
SPARE-2 OUTM		18	18
HU READYM		17	17
HU ON INDM		16	16
LASER ONM		15	15
H/U ON STATUS M		14	14
H/U READY STATUS M		13	13
SPARE-2 OUTM		12	12
L-PHR OK STATUS M		11	11
SPARE 2 INM		10	10
SHUTTER 2 A2M		9	9
SHUTTER 2 A1M		8	8
SHUTTER 2 A0M		7	7
PULSE 4M		6	6
B/G ONM		5	5
H/U ONM		4	4
		3	3
		2	2
		1	1

OPTO-ISOLATOR
OUTPUTS

SOLID STATE RELAY
INPUTS

SOLID STATE RELAY
OUTPUTS
(TO DIGITAL INPUT BOARD)

OPTO-ISOLATOR
INPUTS
(FROM DIGITAL OUTPUT BOARD)

OPTO-ISOLATOR
OUTPUTS

SOLID STATE RELAY
INPUTS

SOLID STATE RELAY
OUTPUTS
(TO DIGITAL INPUT BOARD)

OPTO-ISOLATOR
INPUTS
(FROM DIGITAL OUTPUT BOARD)

APPLIED RESEARCH INC.
6700 ODYSSEY DRIVE HUNTSVILLE AL 35806

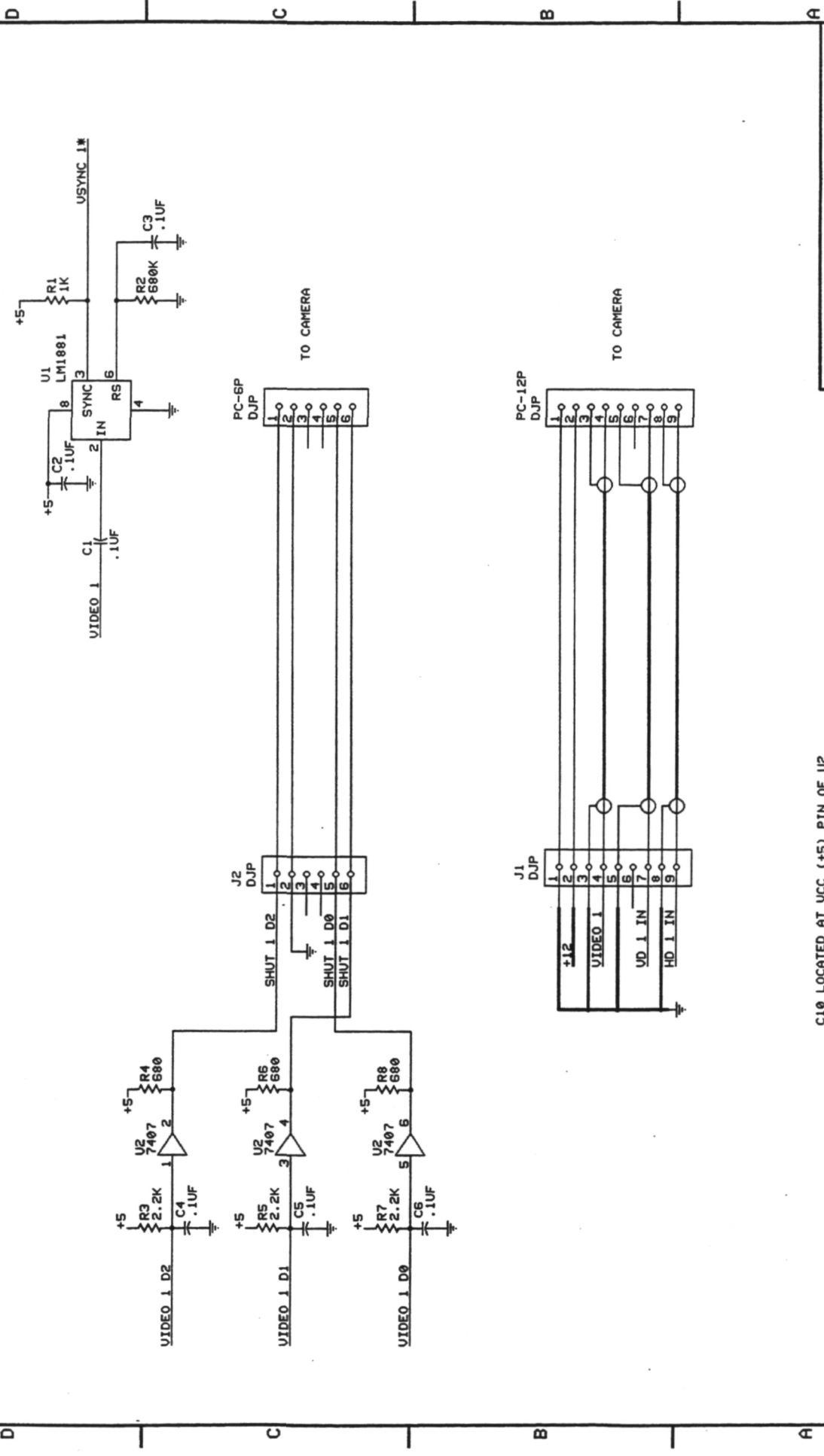
PROFILING IMAGER SYSTEM

ISOLATED I/O BOARD

INSM
HADS MODEL 98P-100
DEVELOPMENT #4906-001

ISOL108D.P03

1 10/25/93



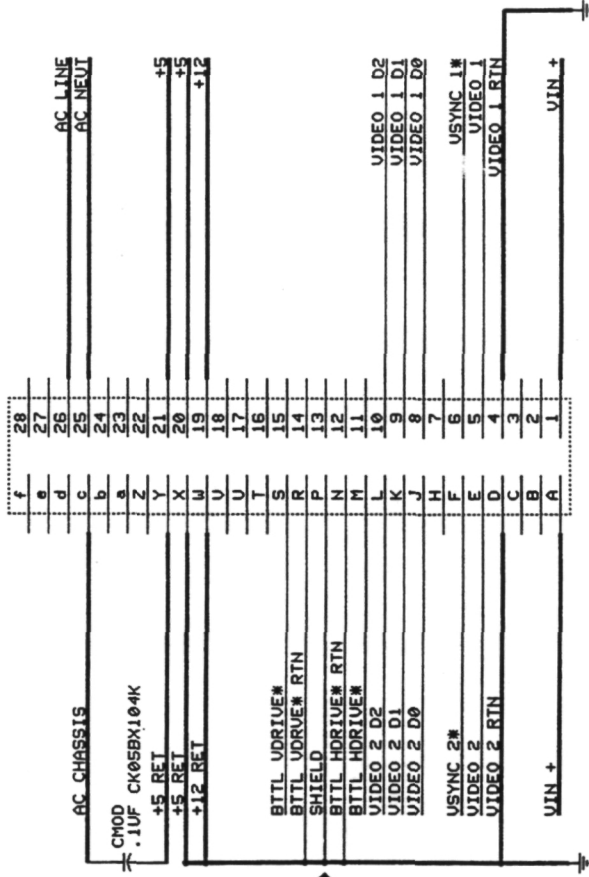
C10 LOCATED AT VCC (+5) PIN OF U2



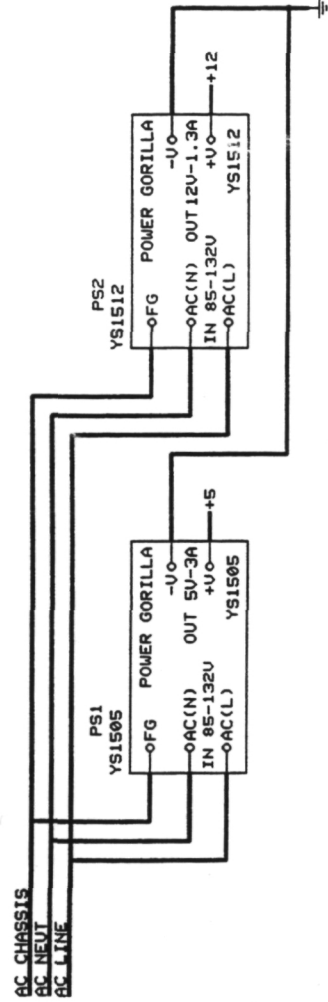
* APPLIED RESEARCH INC. 6700 ODYSSEY DRIVE HUNTSVILLE AL 35806	
TRACKER IMAGER SYSTEM	
D NSM	TRACKER CAMERA BOARD
MACS MODEL 88P-100 DEVELOPMENT #4900-001 TCAMERA.P01	
1	2

CAMERA BOARD

P1
EZM28DREH



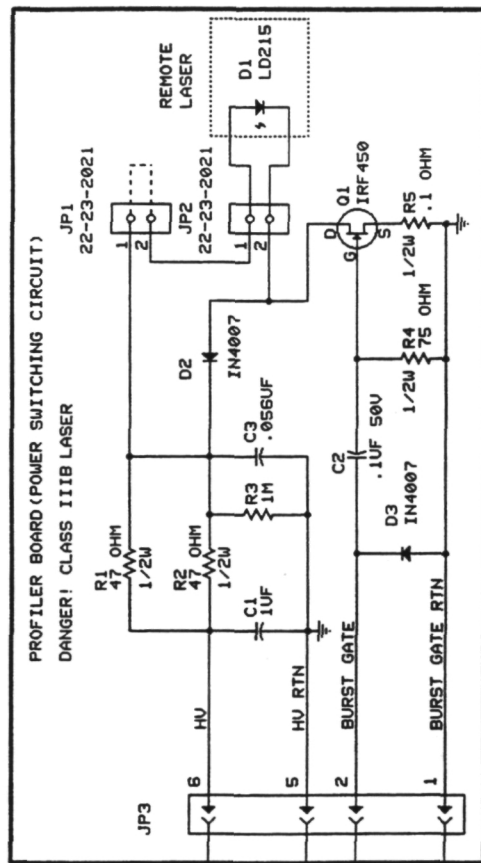
NOTE: BECAUSE OF GROUND LOOP PROBLEMS, THESE TWO GROUND CONNECTIONS WILL ONLY MADE TO THE CAMERA BOARD THAT WILL SOURCE THE U & H DRIVES. (PROFILER/PUDDLE BOARDS)



APPLIED RESEARCH INC.
6700 ODYSSEY DRIVE HUNTSVILLE AL 35806

TRACKER IMAGER SYSTEM
TRACKER CAMERA BOARD
JACS MODEL #BP-100
DEVELOPMENT #4800-001 TCAMERA.P02

REAR PANEL REMOTE IMAGER HOUSING CHANNEL A FRONT PANEL



LASER OUTPUT WINDOW

IMAGING WINDOW

FROM VIDEO IMAGING CTRLR
(SYSTEM PUR-CTLR ASSY)
(HARDWIRED CABLE GROUP)

NOTES:

- C1 = 1UF, 400V METAL POLY (ECO-E4105KF)
- C2 = .1UF, 50V METAL POLY (ECO-V1H104JZ)
- C3 = .056UF, 630V METAL POLY (ECO-E6S63KF)
- R5 = .1 OHM, 1/2W NON INDUCTIVE
- D1 = LASER DIODE LD215C WITH CASE (CATHODE)
- Q1 CASE IS DRAIN

DANGER!
EXTREMELY HIGH VOLTAGE PRESENT



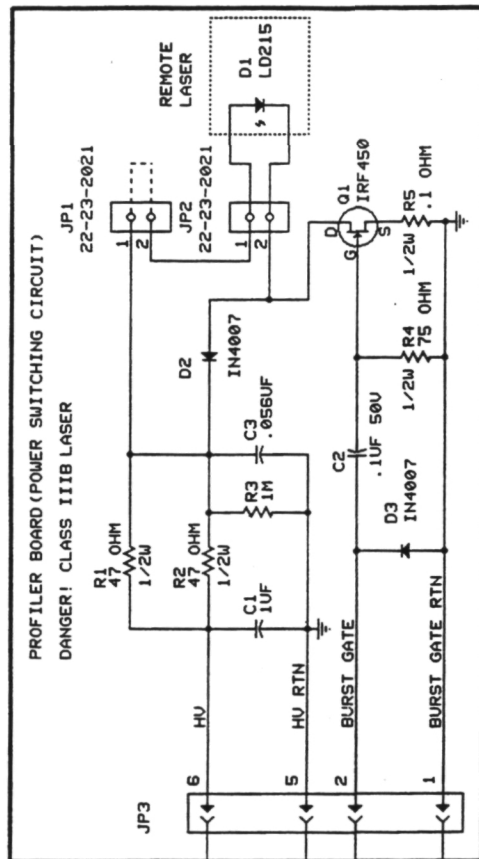
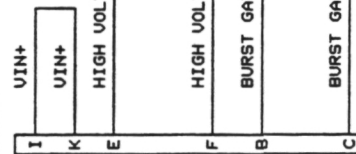
* APPLIED RESEARCH INC. 6700 ODYSSEY DRIVE HUNTSVILLE AL 35806	
TRACKER IMAGER SYSTEM	
D	TRACKER IMAGER BOARD
01/27/94 TIB.P01	

REMOTE IMAGER HOUSING CHANEL B

FRONT PANEL

REAR PANEL

FROM PS1000
SENSOR A
CONNECTOR



FROM VIDEO IMAGING CTRL
(SYSTEM PUR-CTRL ASSY)
(HARDWIRED CABLE GROUP)

IMAGING
PLANE

REMOTE LASER, OPTICAL MIRRORS,
ASSOCIATED LENSES AND FILTERS
AND THEIR MOUNTING ASSEMBLIES

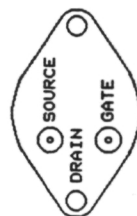
LASER OUTPUT WINDOW

IMAGING WINDOW

NOTES:

- C1 = 1UF, 400V METAL POLY (ECO-E4105KF)
- C2 = .1UF, 50V METAL POLY (ECO-VIH104JZ)
- C3 = .056UF, 630V METAL POLY (ECO-E6563KF)
- R5 = .1 OHM, 1/2W NON INDUCTIVE
- D1 = LASER DIODE LD215C WITH CASE (CATHODE)
- Q1 CASE IS DRAIN

DANGER!
EXTREMELY HIGH VOLTAGE PRESENT



TO-3
Q1 BOTTOM VIEW

APPLIED RESEARCH INC.
6700 ODYSSEY DRIVE HUNTSVILLE AL 35896

TRACKER IMAGER SYSTEM

TRACKER IMAGER BOARD

01/27/94

TIB.P02

8

7

6

5

4

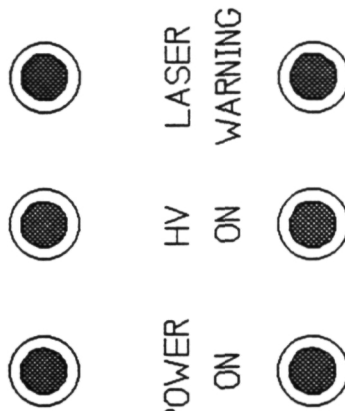
3

2

1

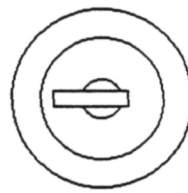
Appendix B Sensor Mechanical Drawings

RESET RESET RESET
HV A HV B TRIGGER



POWER
OFF

INTERLOCK



PS-1000

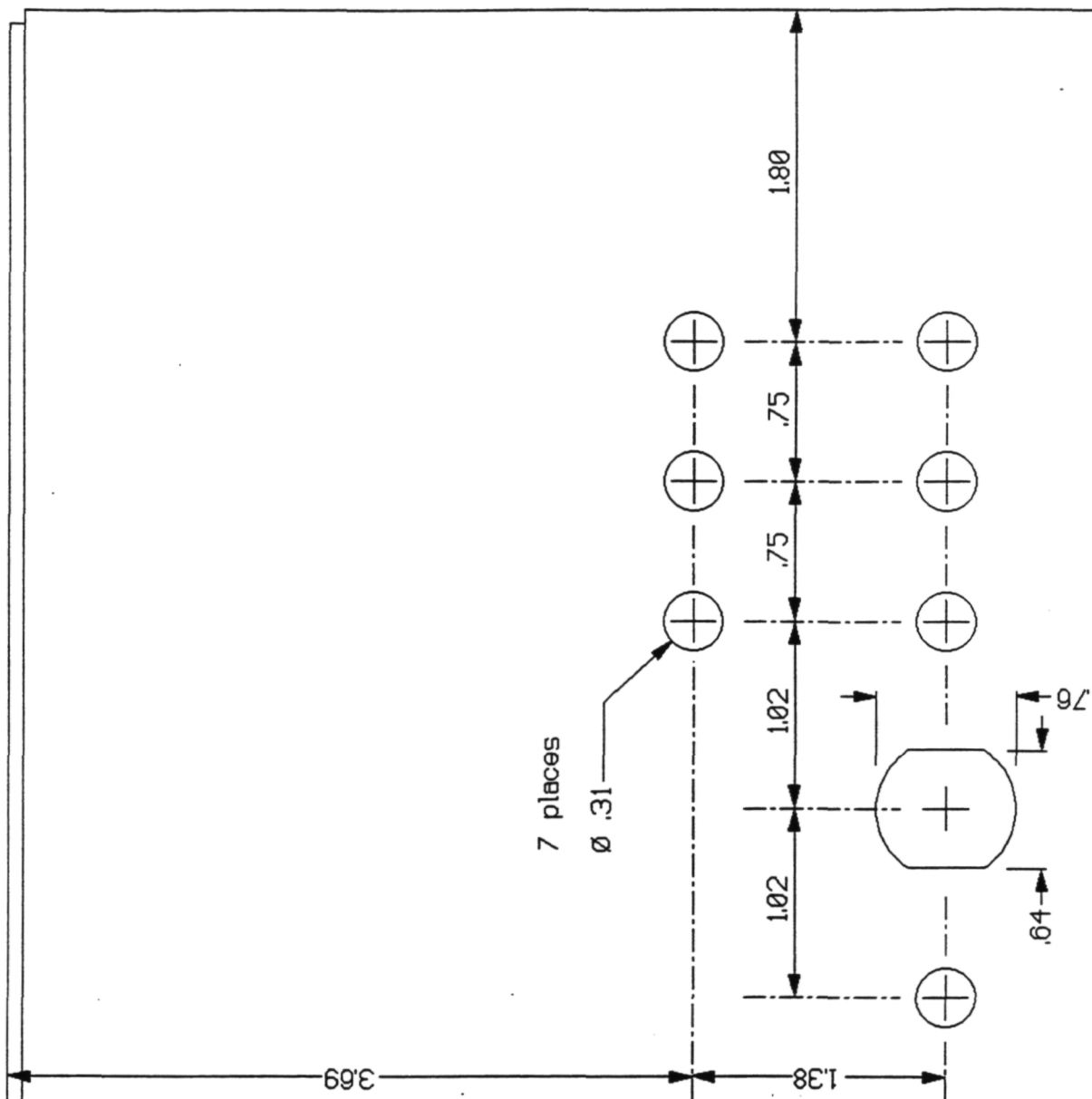
S/N ---

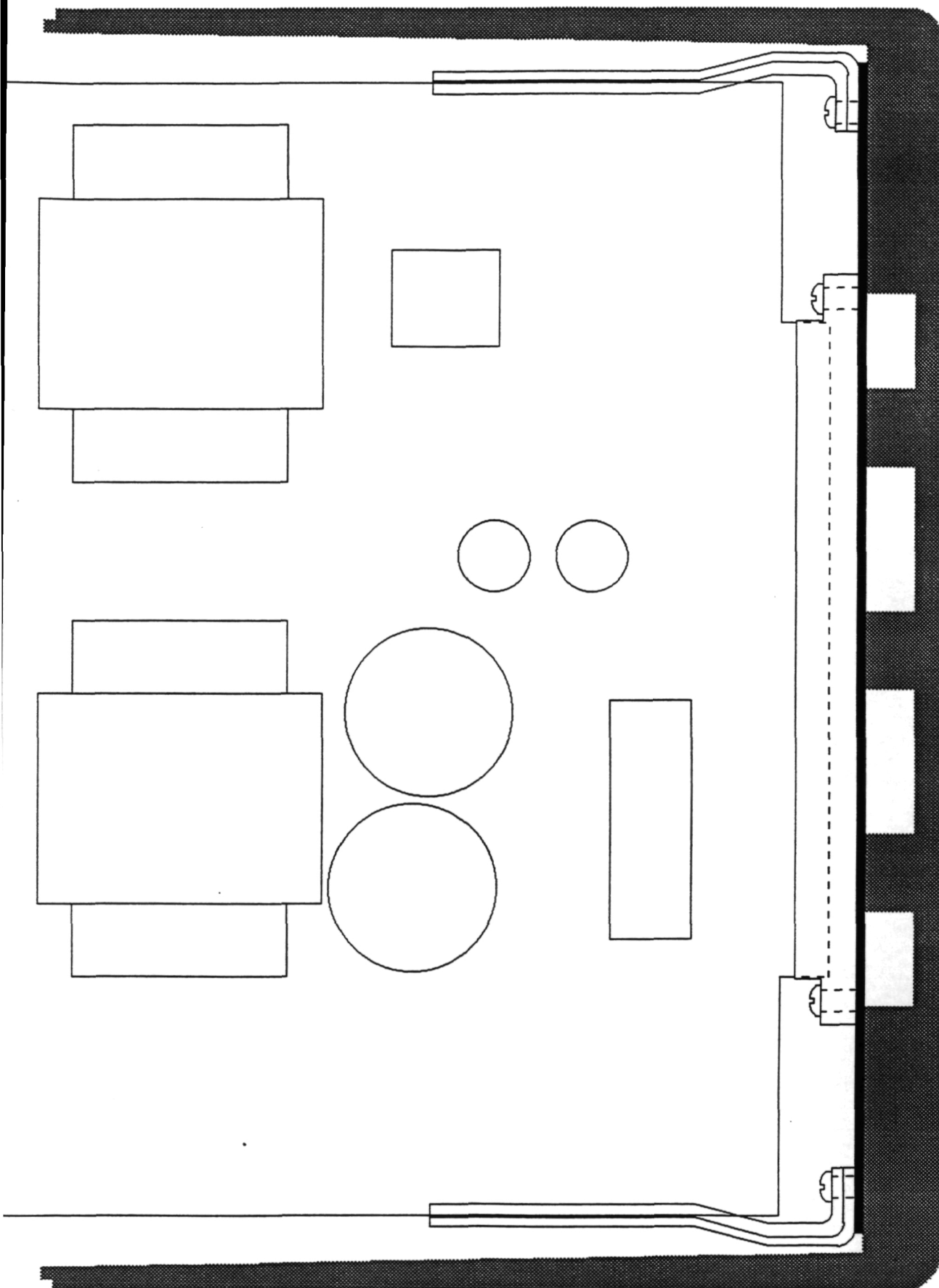
NOTE: The box is painted in (POLANE BLACK SEMI-GROSS) with WHITE Inlay on lettering

PART # 01232018-85

PS-FV,FCD
FRONT VIEW

PS-FD.FCD
FRONT DIMENSION

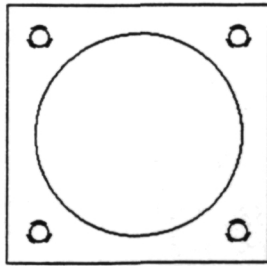




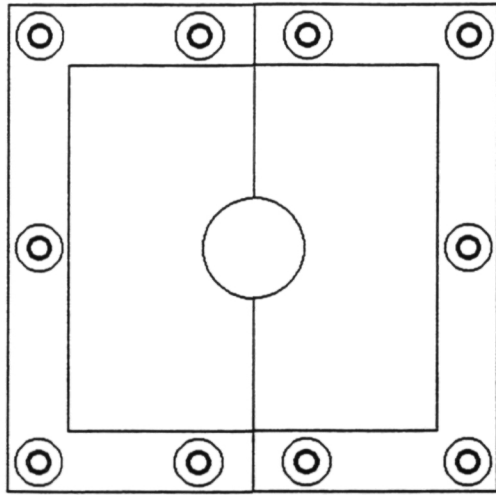
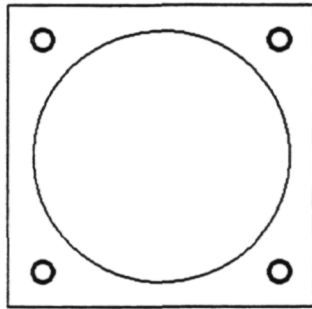
FRONT VIEW

PART # 01232018-85

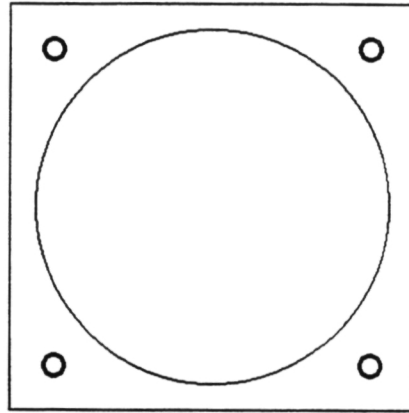
SYNC



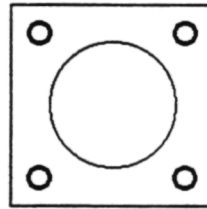
SENSOR A



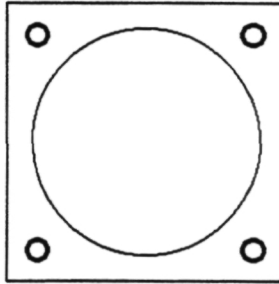
INTERFACE



INTERLOCK



WARNING

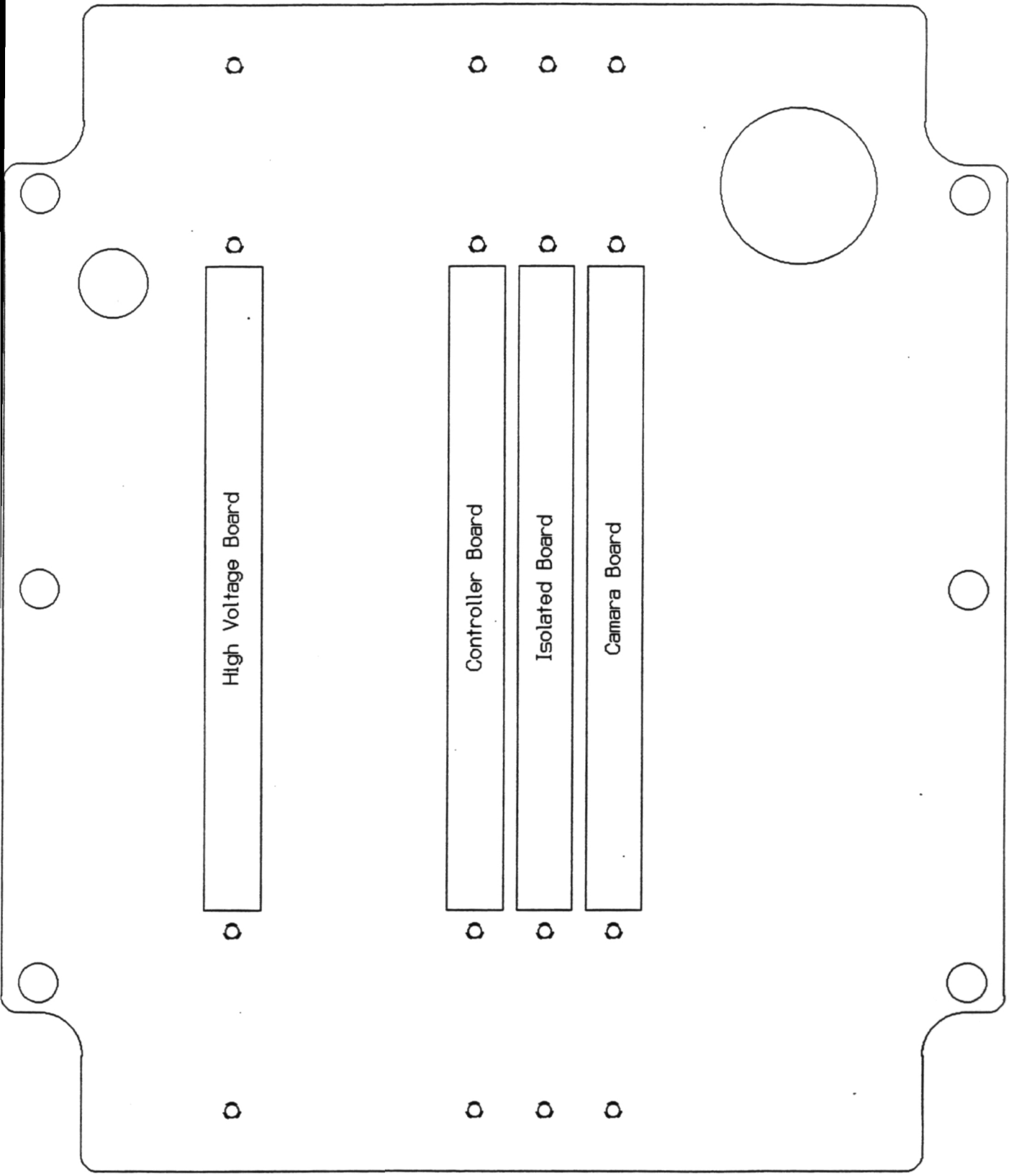


F1

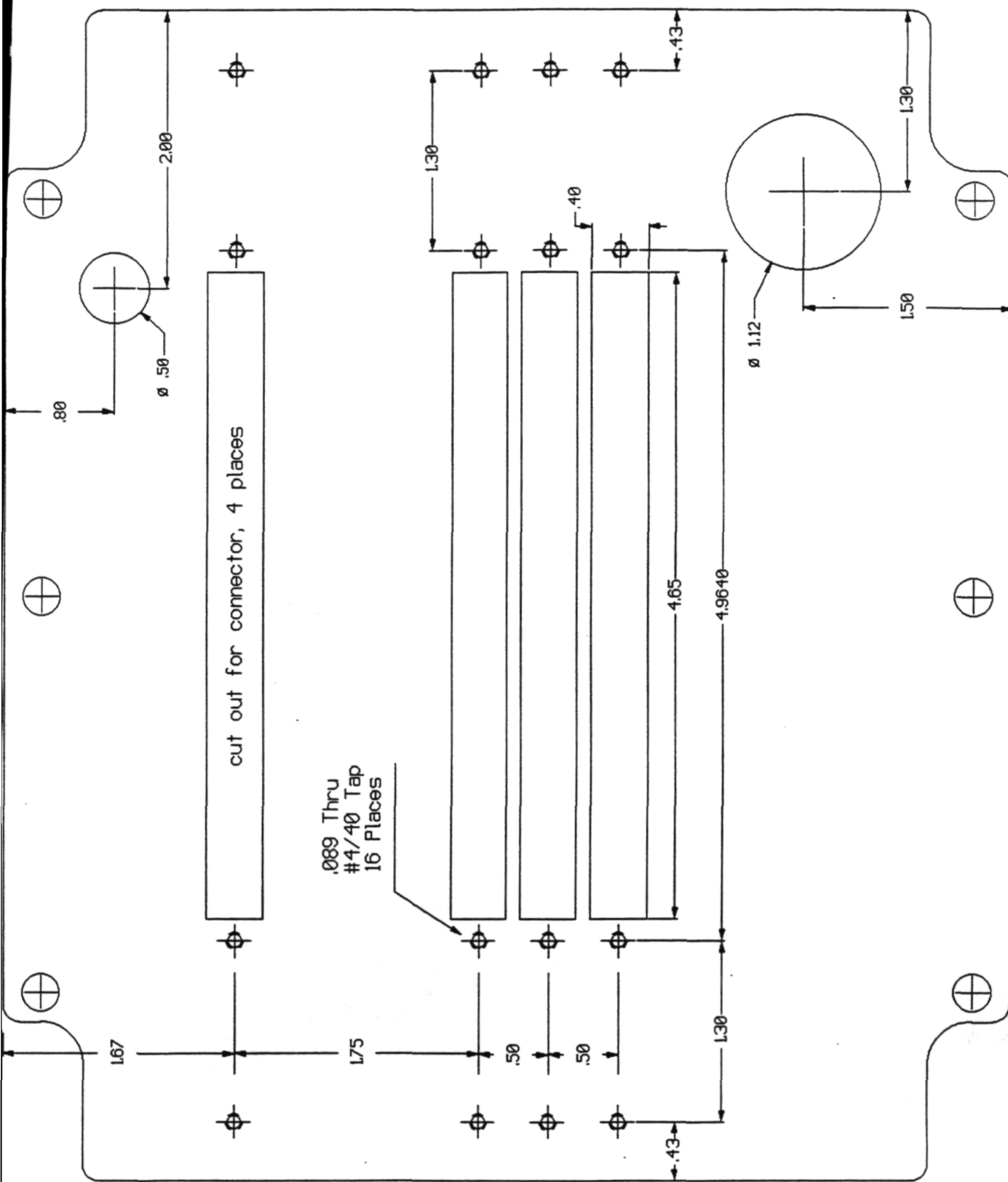


F2





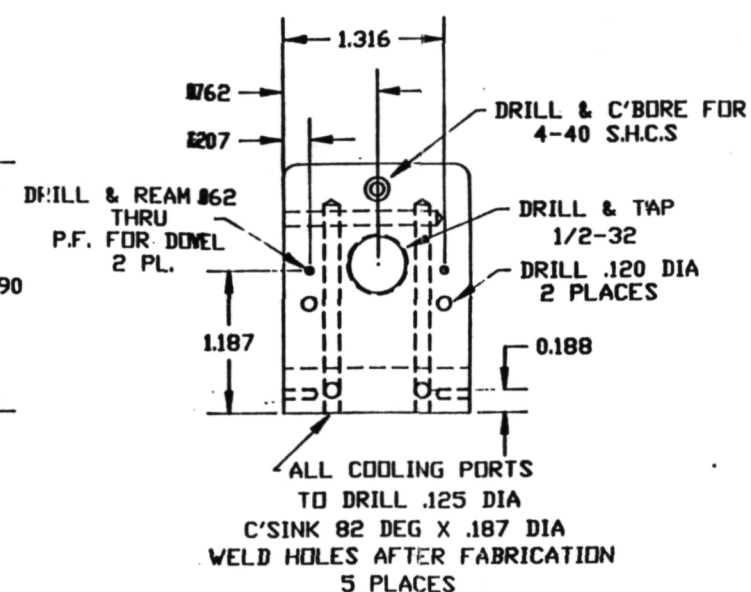
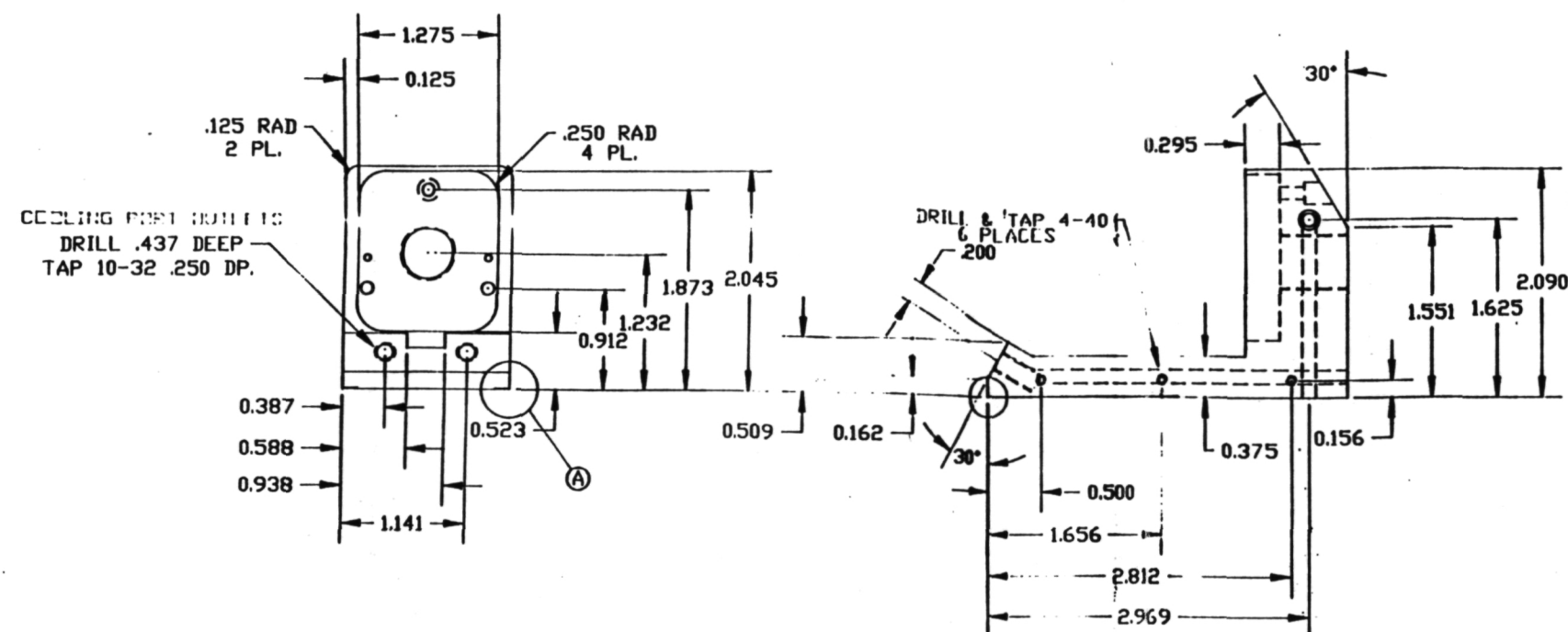
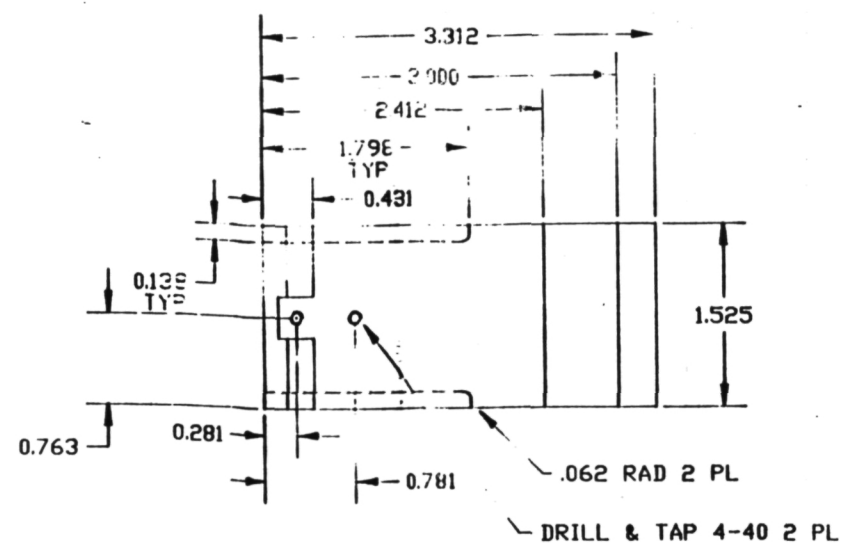
PS-BV,FCD
BOTTOM VIEW



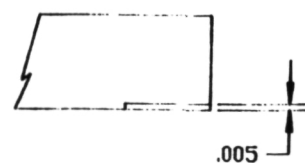
PS-BP,FCD
BOTTOM PLATE

Part # 10089120

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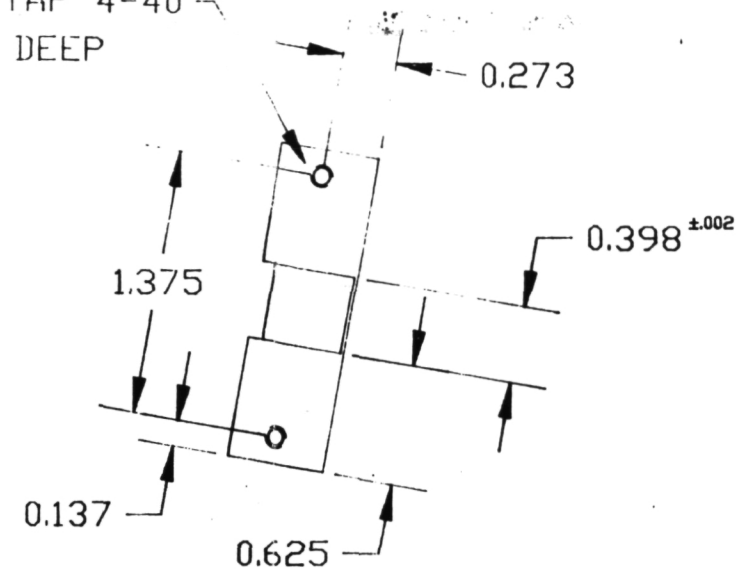
VIEW A



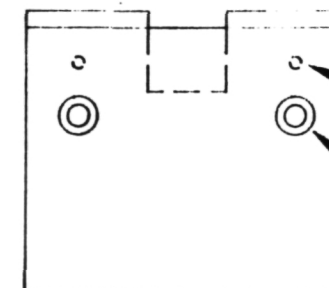
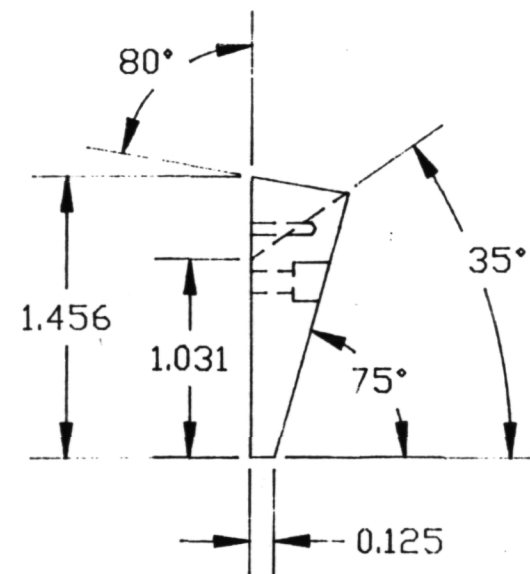
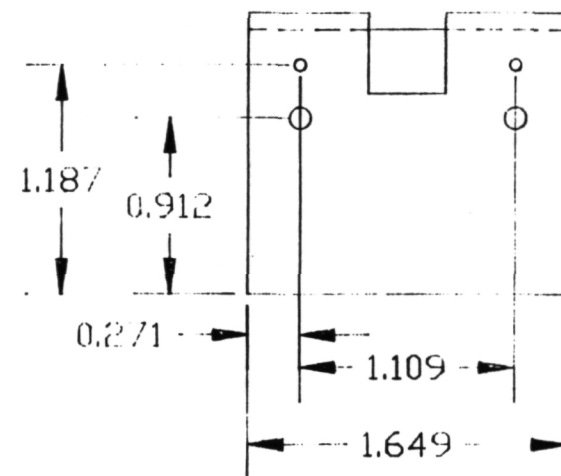
REV	DATE	BY	APPROVED	REVISION DESCRIPTION
MATERIAL	QTY	TOLERANCE	UNLESS OTHERWISE NOTED	BROOKS MACHINE & TOOL, INC. 3410 6TH AVE. HUNTSVILLE, AL. 35805
6061-T6 AL.		.X ± .030		
		.XX ± .010		
		.XXX ± .005		
		ANGLES MIN ± 1 DEG		PART NAME
SCALE		DWG NO.		WELD PUDDLE IMAGER BASE
FULL		AR221		

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DRILL & TAP 4-40
1/2" DEEP



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DRILL .067 DIA
FAR SIDE .312 DIA

DRILL & C'BORE FOR
4-40 S.H.C.S.

REV	DATE	BY	APPROVED
MATERIAL	QTY	TOLERANCE UNLESS OTHERWISE NOTED	
6061-T6 AL.		.X ±	.030
		.XX ±	.010
		.XXX ±	.005
		ANGLES TO BE ± 1 DEG	
SCALE	DWG NO.		
FULL			AR222

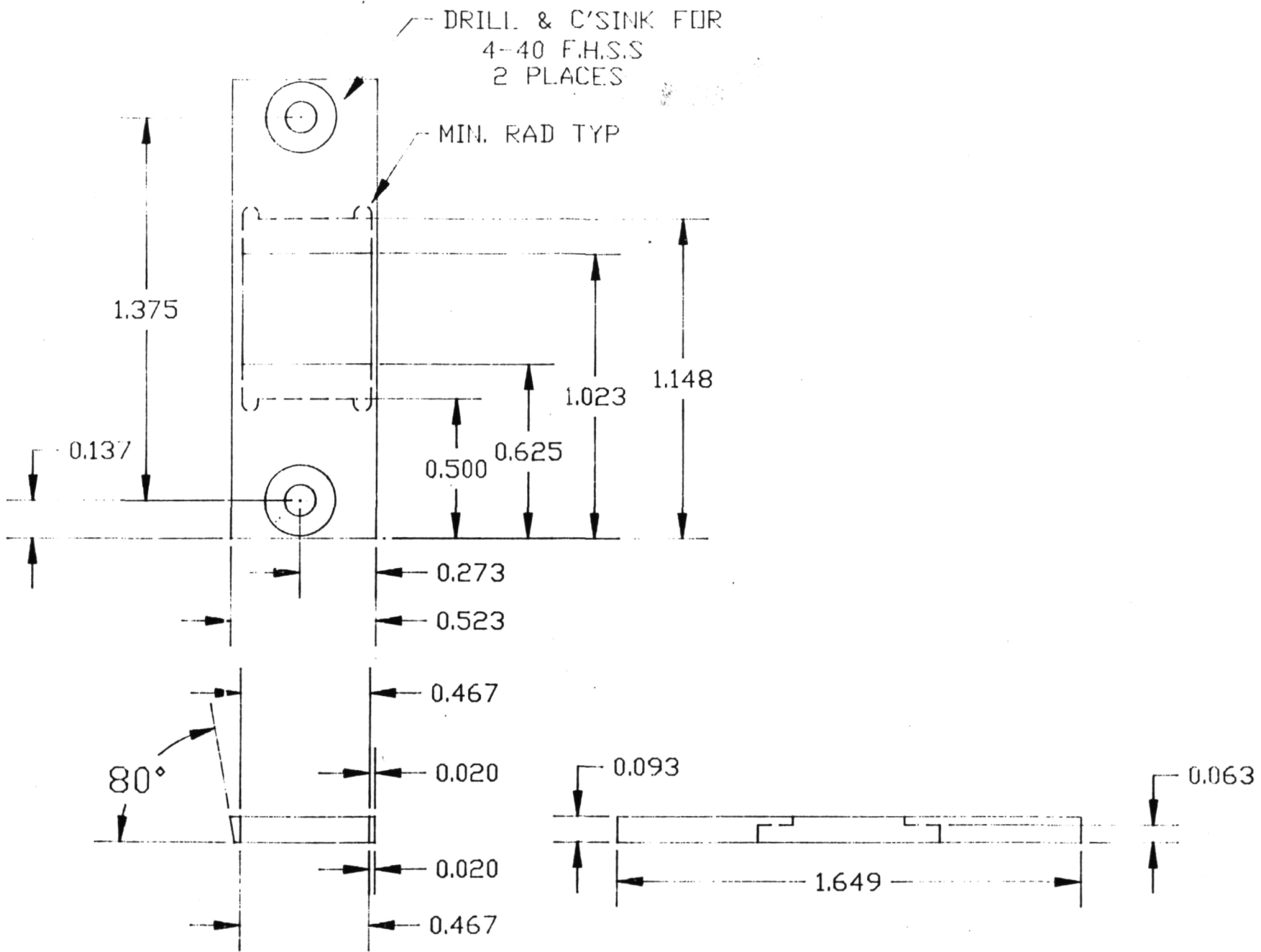
REVISION DESCRIPTION

BROOKS MACHINE & TOOL, INC.
3410 6TH AVE. HUNTSVILLE, AL 35894

PART NAME

WELD PUDDLE MACHINER
PRISM MOUNT

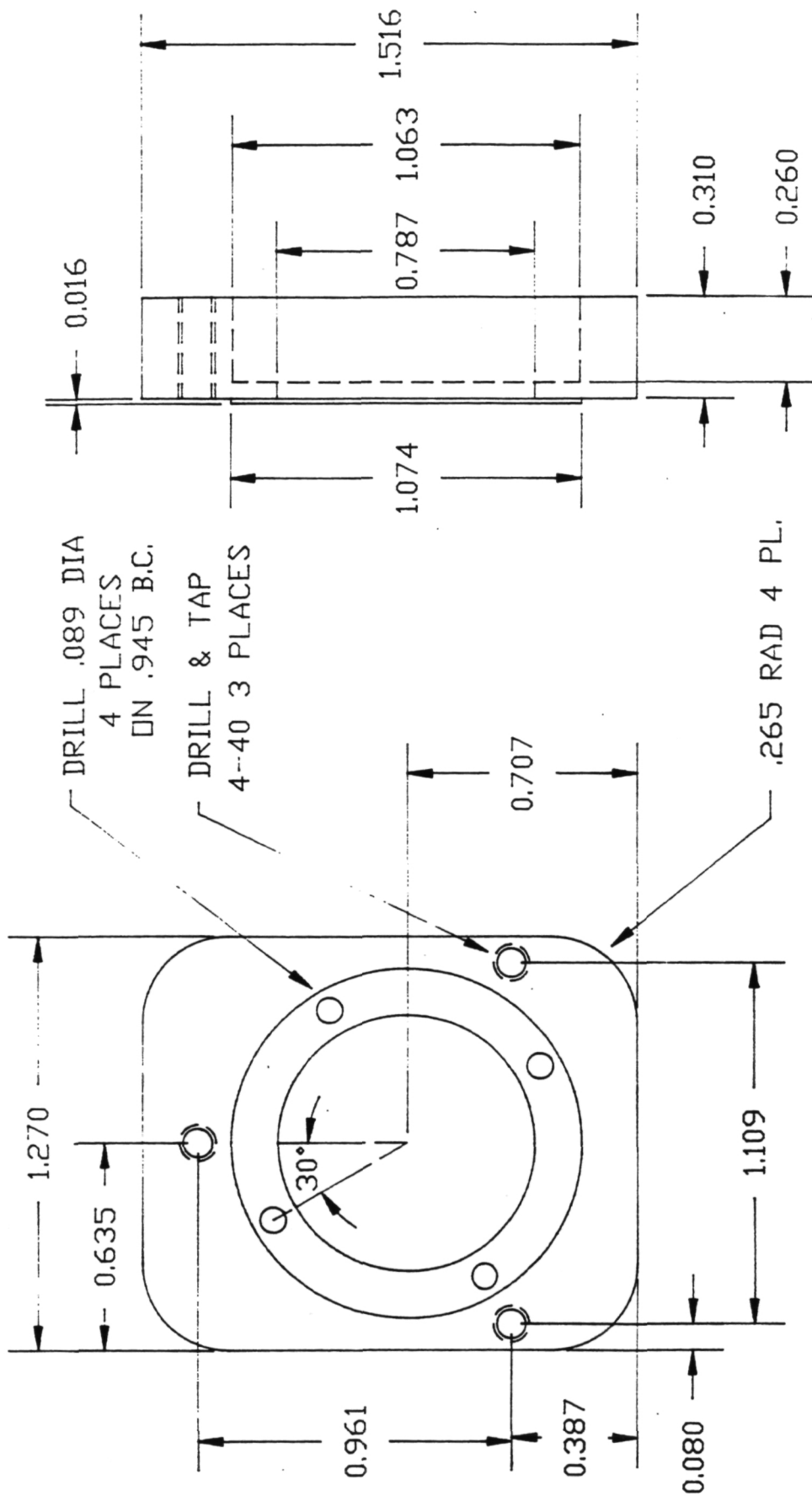
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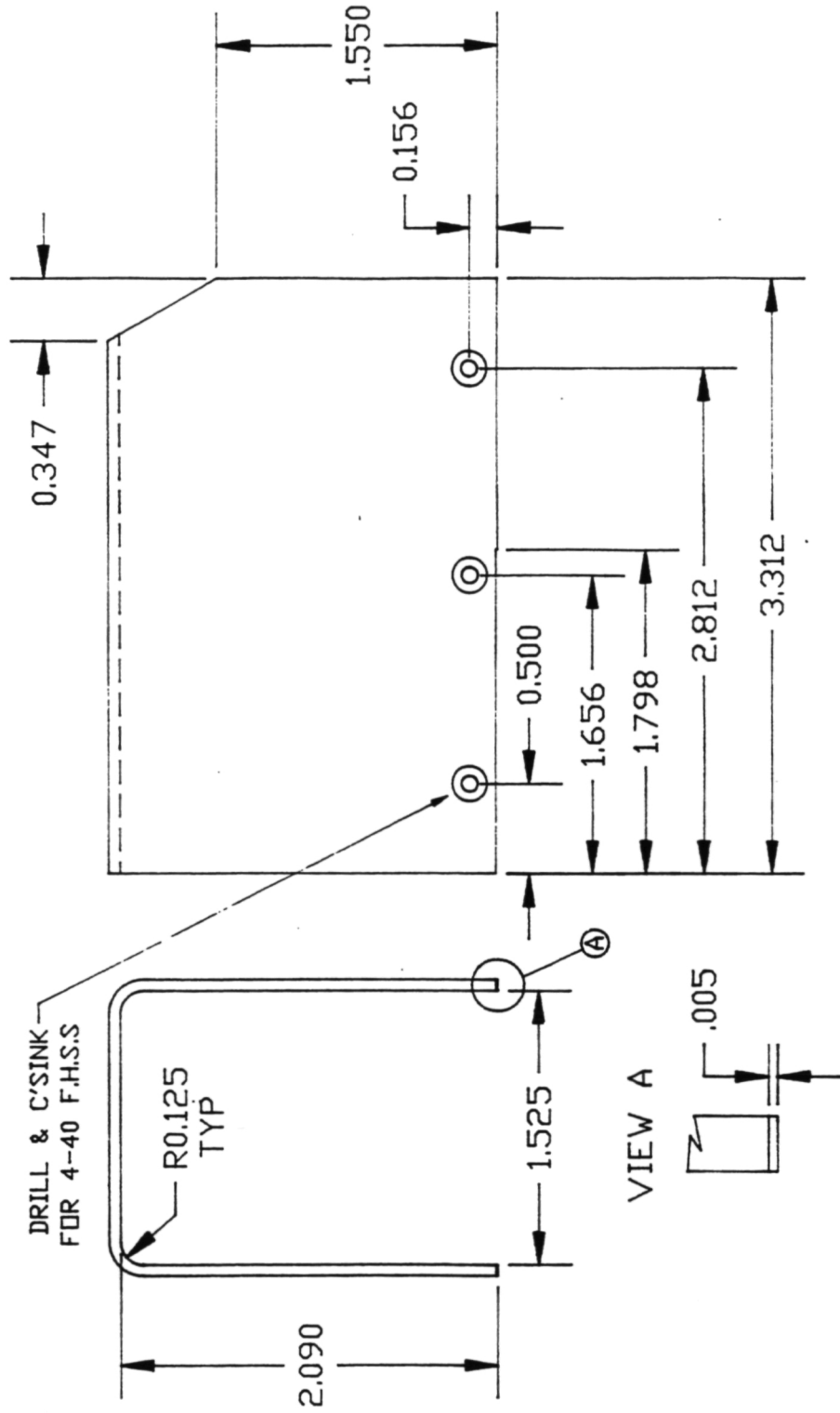
REV	DATE	BY	APPROVED
MATERIAL	QTY	TOLERANCE UNLESS OTHERWISE NOTED	
6061-T6 AL.		.X ±	.030
		.XX ±	.010
		.XXX ±	.005
		ANGLES TO BE ± 1 DEG	
SCALE	2X	DWG NO.	AR223

REVISION DESCRIPTION
BROOKS MACHINE & TOOL, INC.
3410 6TH AVE. HUNTSVILLE, AL 35805
PART NAME
WELD PUDDLE IMAGER
PRISM COVER



REV	DATE	BY	APPROVED
MATERIAL	QTY	TOLERANCE UNLESS OTHERWISE NOTED	
6061-T6 AL.	1	.X ± .030	
		.XX ± .010	
		.XXX ± .005	
		ANGLES TO BE ± 1 DEG	
		DVG NO.	
SCALE		AR224	
2X			

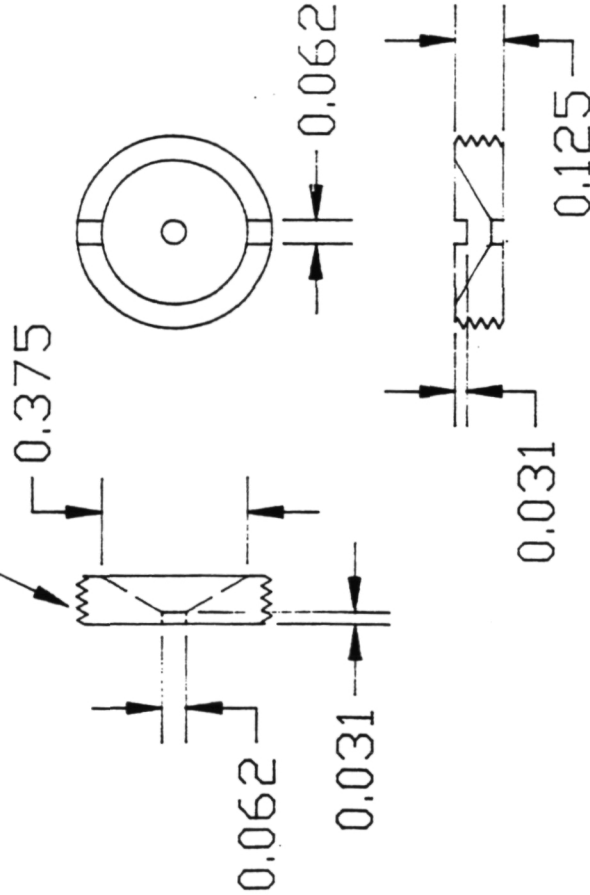
MATERIAL .062 ALUMINUM



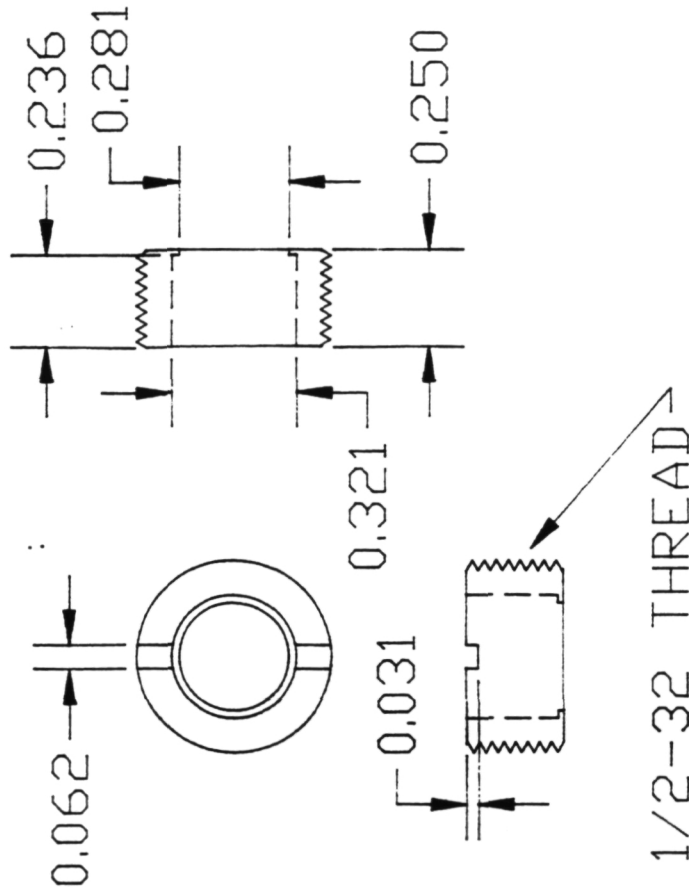
REV	DATE	BY	APPROVED
MATERIAL	QTY	TOLERANCE UNLESS OTHERWISE NOTED	REVISION DESCRIPTION
ALUMINUM		.X ± .030	BROOKS MACHINE & TOOL, INC.
		.XX ± .010	3410 6TH AVE. HUNTSVILLE, AL. 35805
		.XXX ± .005	PART NAME
		ANGLES TO BE ± 1 DEG	WELD PUDDLE IMAGER
		DWG NO.	CAMERA COVER
SCALE	FULL		
	AR225		

IRIS

1/2-32 THREAD

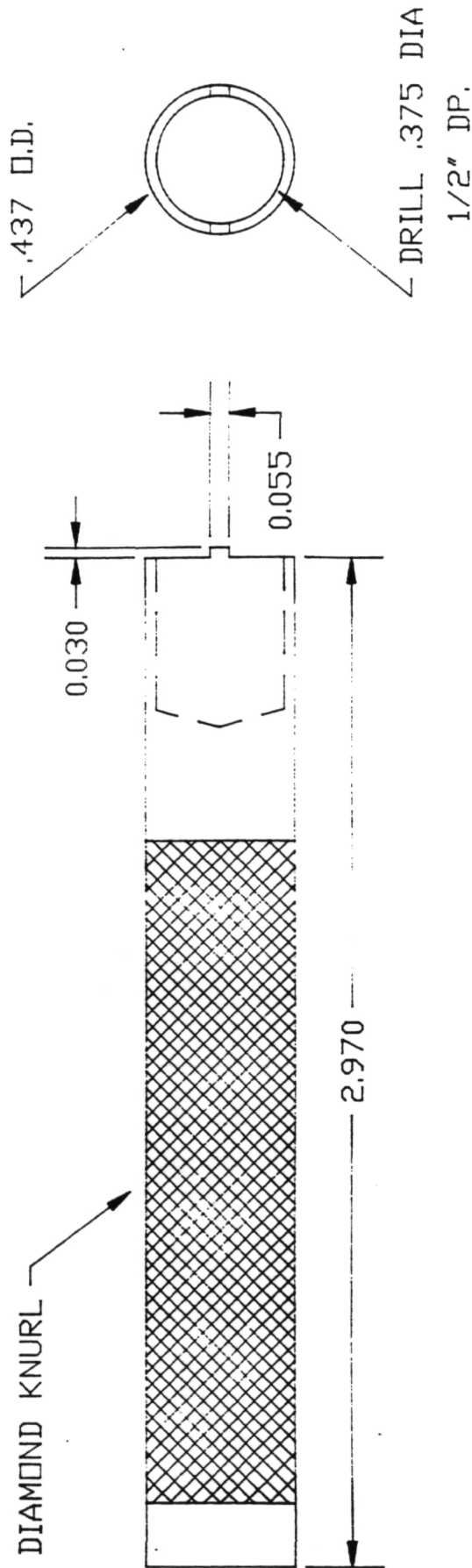


LENS MOUNT



REV	DATE	BY	APPROVED
MATERIAL	QTY	TOLERANCE UNLESS OTHERWISE NOTED	
6061-T6 AL.		.X ± .030	
		.XX ± .010	
		.XXX ± .005	
		ANGLES TO BE ± 1 DEG	
SCALE	2X	DWG NO.	AR226

REVISION DESCRIPTION
BROOKS MACHINE & TOOL, IHC, 3410 6TH AVE. HUNTSVILLE, AL. 35805
PART NAME WELD PUDDLE IMAGER LENS MOUNT & IRIS

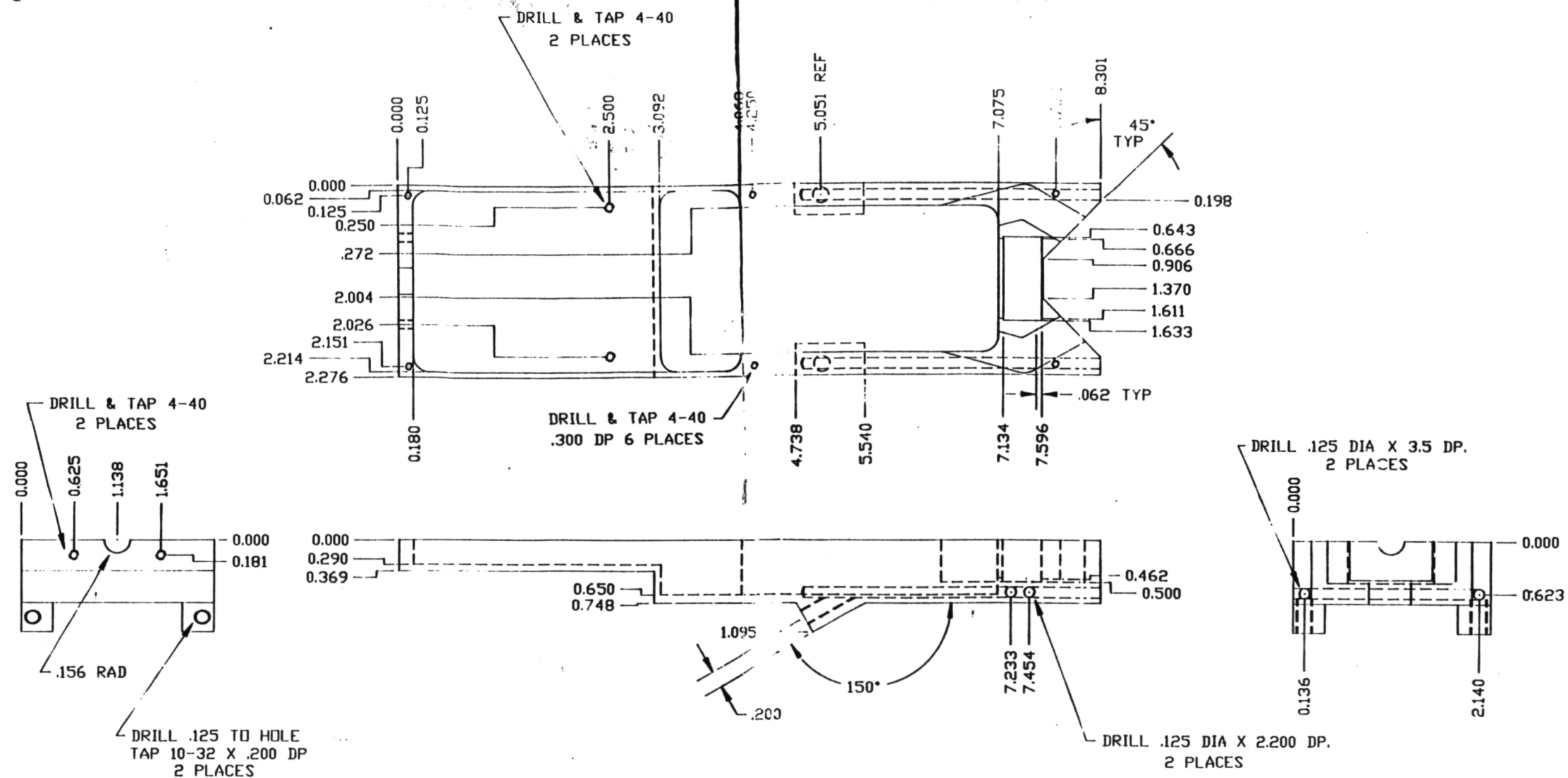


REV	DATE	BY	APPROVED
MATERIAL	QTY	TOLERANCE UNLESS OTHERWISE NOTED	
S.S.		.X ± .030	
		.XX ± .010	
		.XXX ± .005	
		ANGLES TO BE ± 1 DEG	
SCALE	2X	DWG NO.	AR227

REVISION DESCRIPTION
 BROOKS MACHINE & TOOL, INC.
 3410 6TH AVE. HUNTSVILLE, AL. 35805
 PART NAME
 WELD PUDDLE IMAGER
 INSERTION TOOL.

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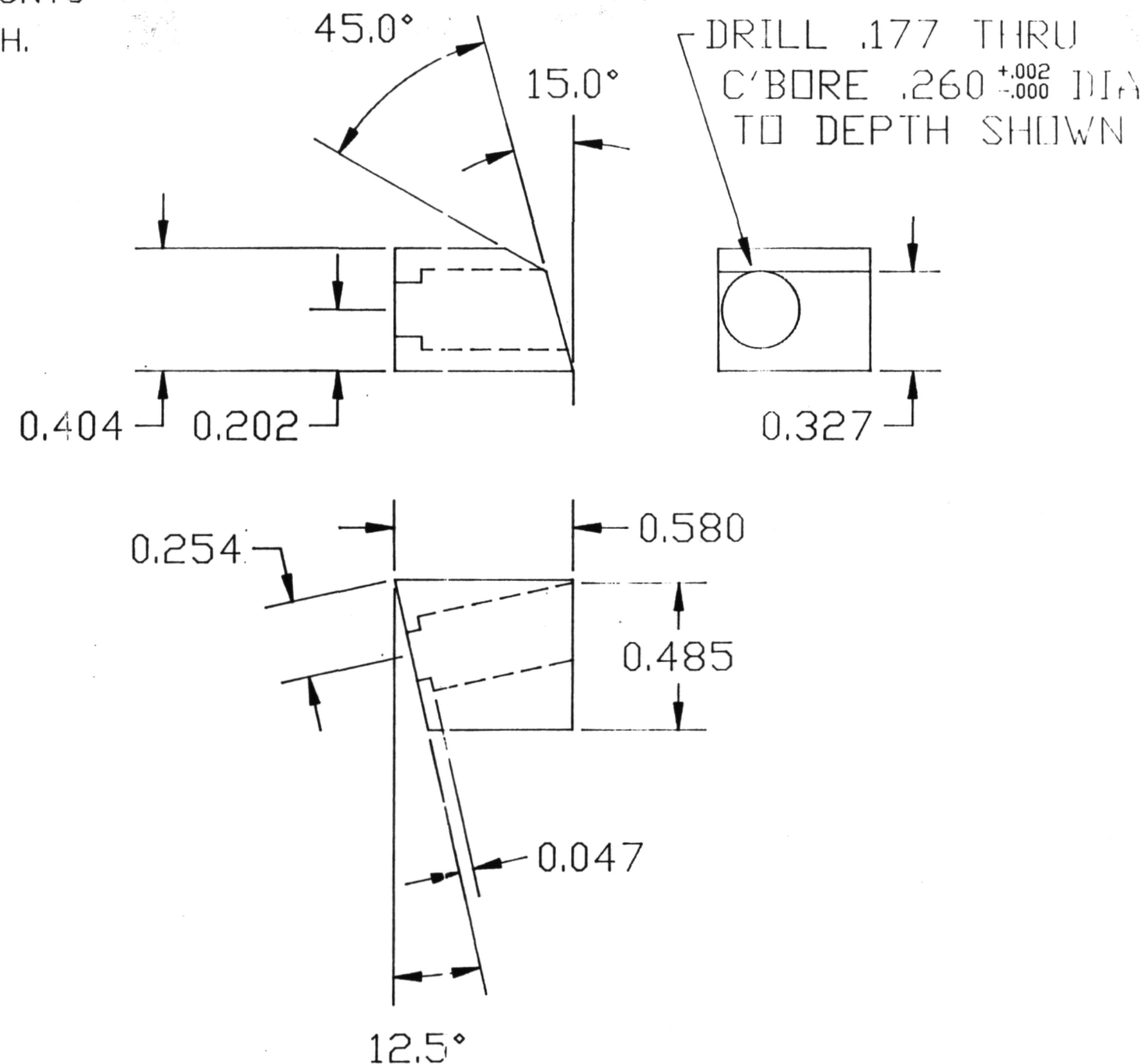
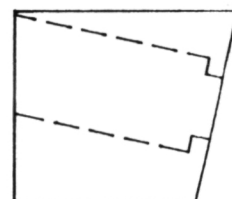
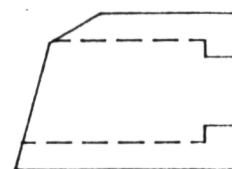
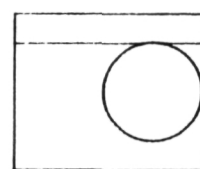
REV	DATE	BY	APPROVED	REVISION DESCRIPTION
MATERIAL	QTY	TOLERANCE UNLESS OTHERWISE NOTED		BROOKS MACHINE & TOOL, INC.
6061-T6 AL.		.X ±	.030	3410 6TH AVE. HUNTSVILLE, AL. 35805
		.XX ±	.010	PART NAME
		.XXX ±	.005	NEW SEAMTRACKER
		ANGLES TO BE ± 1 DEG		BOTTOM BASE
SCALE	DWG NO.			
FULL	AR231			

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BOTTOM LASER MOUNTS

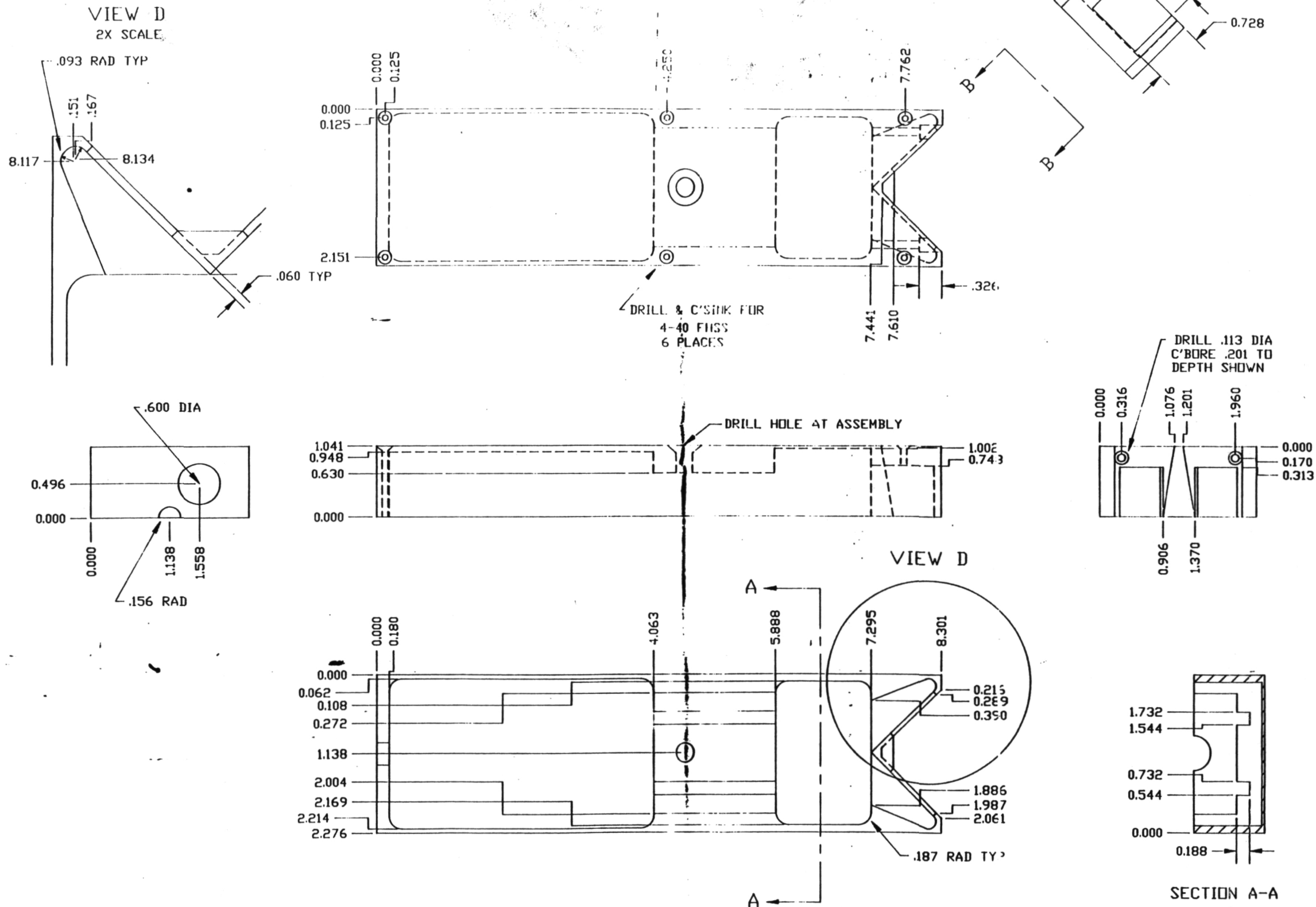
QTY: 1 L.H. 1 R.H.



REV	DATE	BY	APPROVED	REVISION DESCRIPTION
MATERIAL	QTY	TOLERANCE UNLESS OTHERWISE NOTED		BROOKS MACHINE & TOOL, INC. 3410 6TH AVE. HUNTSVILLE, AL 35805 PART NAME NEW SEAMTRACKER SPOT LASER MOUNTS
DELIN		.X ±	.030	
		.XX ±	.010	
		.XXX ±	.005	
		ANGLES TO BE ± 1 DEG		
SCALE	2X	DWG NO.	AR232	

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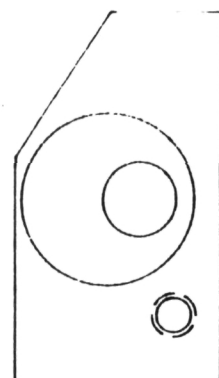
REV	DATE	BY	APPROVED	REVISION DESCRIPTION	
MATERIAL	QTY	TOLERANCE UNLESS OTHERWISE NOTED		BROOKS MACHINE & TOOL, INC. 3410 6TH AVE. HUNTSVILLE, AL. 35805	
6061-T6 AL.		.X ± .030			
		.XX ± .010			
		.XXX ± .005			
		ANGLES TO BE ± 1 DEG		PART NAME	
SCALE		IF NO INL	AR233	NEW SEAMTRACKER TOP BASE	
FULL					

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TOP LASER MOUNTS

QTY: 1 L.H. 1 R.H.

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DRILL & TAP 4-40

0.952

0.281

0.577

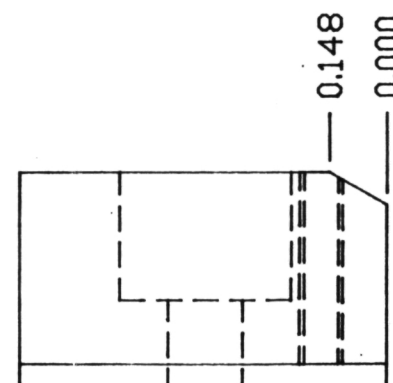
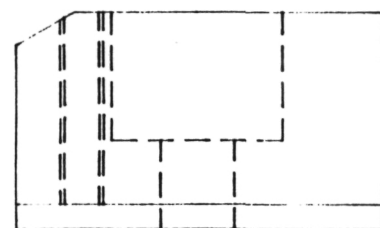
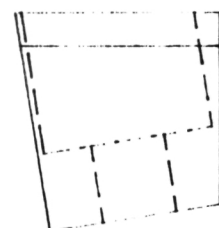
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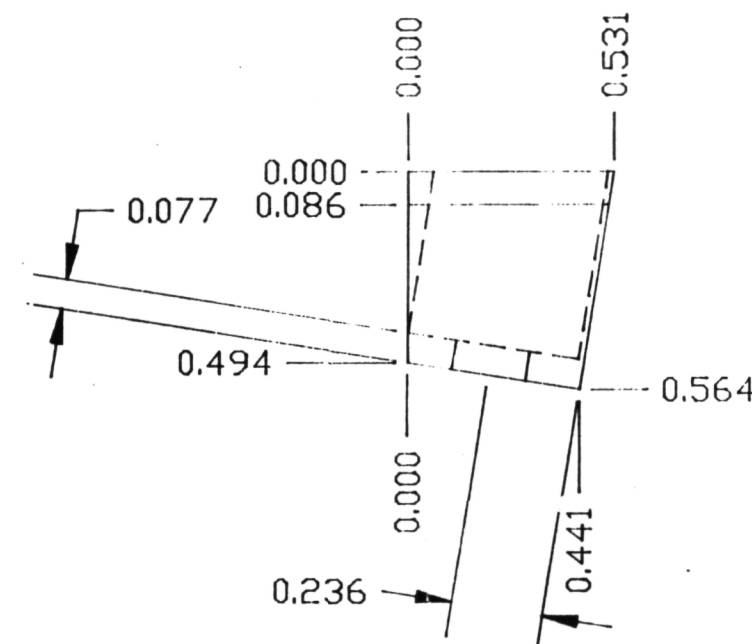
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DRILL .192 DIA
C'BORE .447 DIA
TO DEPTH SHOWN



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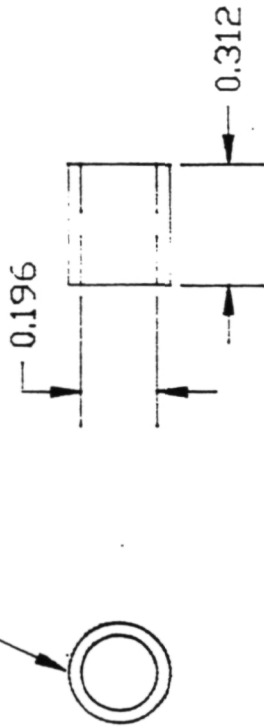


MIRROR IMAGE AS SHOWN

REV	DATE	BY	APPROVED
MATERIAL	QTY	TOLERANCE UNLESS OTHERWISE NOTED	
6061-T6 AL.		.X ±	.030
		.XX ±	.010
		.XXX ±	.005
		ANGLES TO BE ± 1 DEG	
SCALE	2X	DWG NO.	AR234

REVISION DESCRIPTION	
BROOKS MACHINE & TOOL, INC.	
3410 6TH AVE. HUNTSVILLE, AL. 35805	
PART NAME	NEW SEAMTRACKER
	HIGH POWERED LASER MOUNT

OUTSIDE DIAMETER TO BE
LIGHT PUSH FIT IN AR232

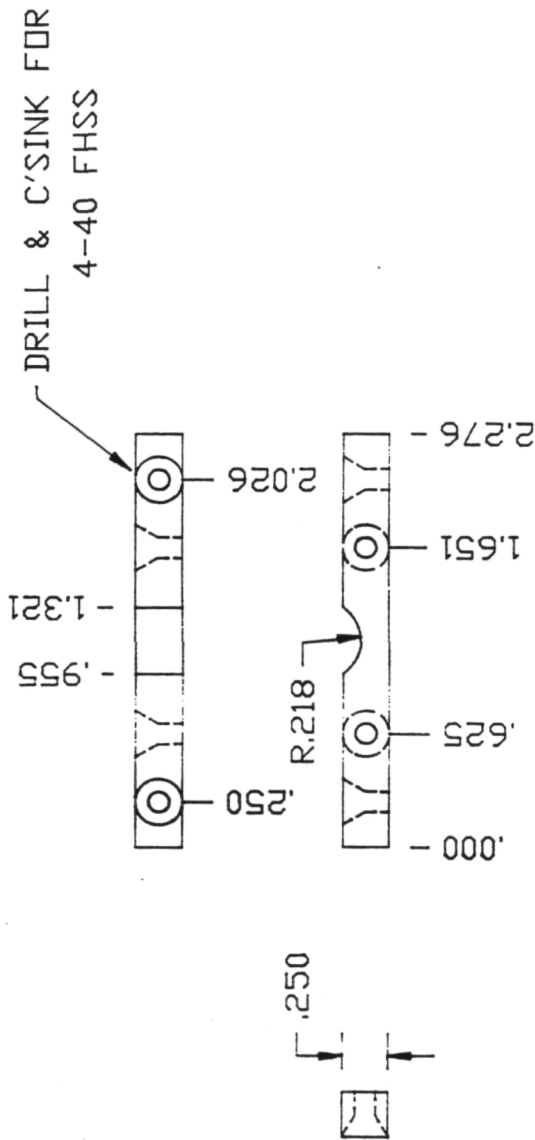


REV	DATE	BY	APPROVED	REVISION DESCRIPTION
MATERIAL 6061-T6 AL.	QTY 2	TOLERANCE UNLESS OTHERWISE NOTED		BROOKS MACHINE & TOOL, INC. 3410 6TH AVE. HUNTSVILLE, AL. 35805
		.X ± .030		
		.XX ± .010		
		.XXX ± .005		PART NAME
		ANGLES TO BE ± 1 DEG		NEW SEAMTRACKER
SCALE 2X		DWG NO. AR235		LASER COLLIMATOR SLEEVE

REAR SEAMTRACKER MOUNT

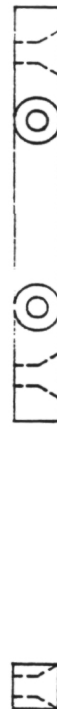
MAT: ALUMINUM

QTY 1



FRONT SEAMTRACKER MOUNT

QTY: 1



PART IDENTICAL TO ABOVE WITHOUT RADIUS

REV	DATE	BY	APPROVED	REVISION DESCRIPTION
MATERIAL	QTY	TOLERANCE UNLESS OTHERWISE NOTED		
		.X ± .030		
		.XX ± .010		
		.XXX ± .005		
		ANGLES TO BE ± 1 DEG		
SCALE	FULL	DWG NO.	AR252	
				PART NAME TORCH ASSEMBLY
				SEAMTRACKER MOUNTS
				BROOKS MACHINE & TOOL, INC.
				3410 6TH AVE. HUNTSVILLE, AL. 35805